MANCHESTER
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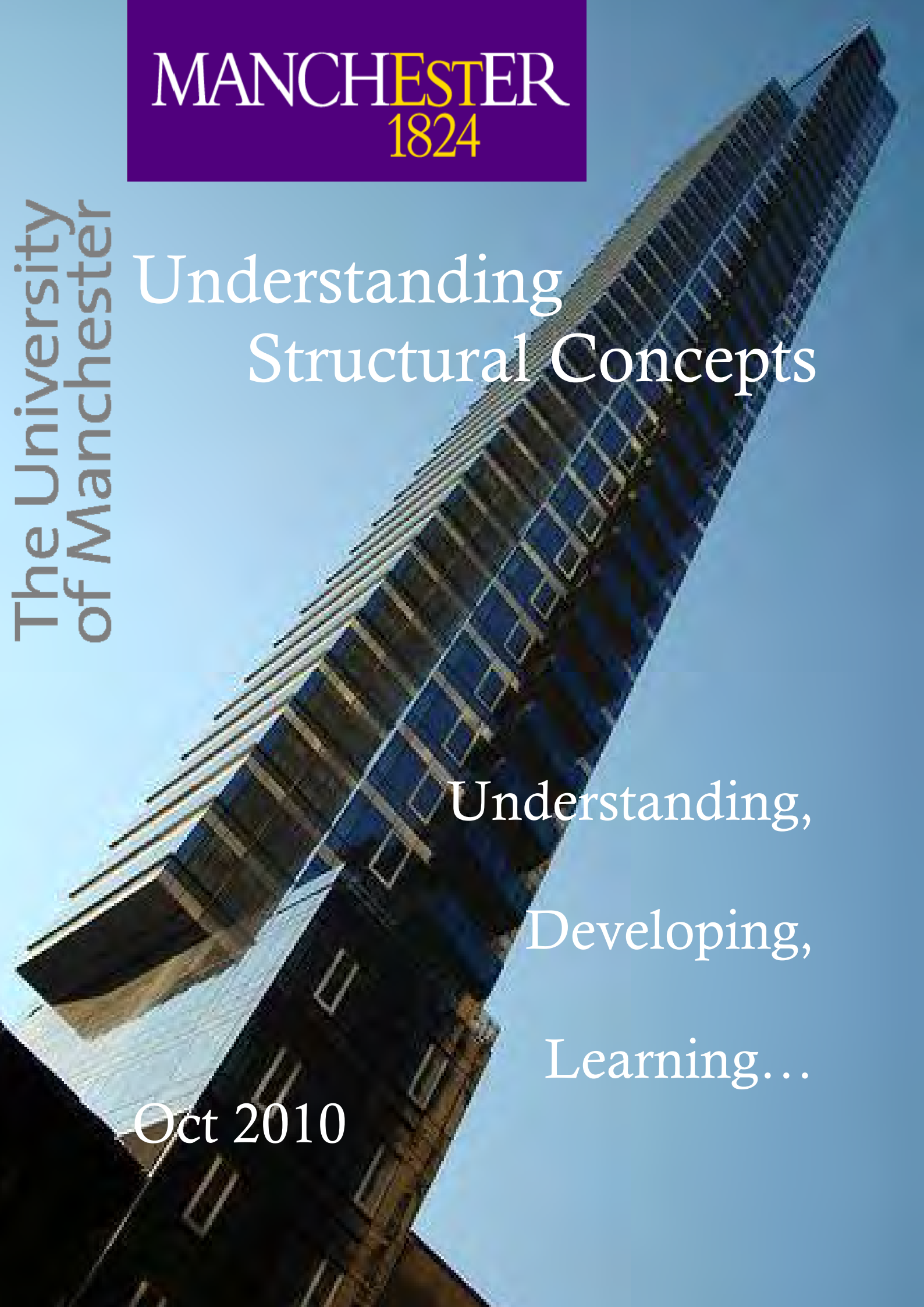
The University of Manchester

# Understanding Structural Concepts



Understanding,

Developing,

Learning…

Oct 2010

# Preface

This booklet is a collection of students' coursework on, *"Understanding structural concepts",* which is part of the module Research Methods in 2010-11 at The University of Manchester. The booklet forms a source of learning for the students themselves enabling them to learn from each other rather than from lecturers and textbooks.

It is hoped that students learn effectively and actively and this, in part, requires appropriate activities and/or stimulators being provided. Students were asked to study, *Seeing and Touching Structural Concepts*, at the website, www.structuralconcepts.org, where structural concepts are demonstrated by physical models and their applications are shown by practical examples. It was hoped that students could not only quickly revise a number of concepts they studied previously but could also gain an improved understanding of the structural concepts.

*Enhancing the understanding of structural concepts* was introduced to the module in 2006 when the website was available internally and students were asked to do a piece of related individual coursework. After reading through the coursework, we felt that the individual submissions were interesting and varied and included some creative components. The coursework was revised and improved on the basis of the previous submissions in the years of 2007 and 2008. It was hoped that the revised coursework would encourage students to consider and explain structural concepts in a simple manner and to look for examples of structural concepts in everyday life motivating further study and the development of a greater understanding and awareness of structural concepts.

All the submissions were made through Blackboard. They are slightly edited for the consistence of the format and compiled into one single PDF file. The booklet written by the students is 'published' through Blackboard so that they could learn from the work of each other and further improve their understanding of structural concepts. The booklet can be downloaded by the students and kept by them.

The coursework return was very good. 52 submissions were received from a class of 48, including 30 model demonstrations and 22 examples plus 4 video clips. As the lecturer, I have enjoyed when reading through the coursework.

There was no clear distinction between some of the models and examples provided and included in this booklet as some models can be treated as examples and vice versa. The titles in the contents page are directly copied from the coursework.

Mr. Qingwen Zhang, a PhD student, compiled all the submissions into one single word file and produced the contents page then compressed the huge file into a much smaller PDF file allowing downloading possible.

We hope all students taking Research Methods will enjoy reading the presentation of their work in this booklet and will have learned from each other.

Tianjian Ji

1 November 2010

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# Models

# 1.1 Effect of Bracings in the deformation of Joints

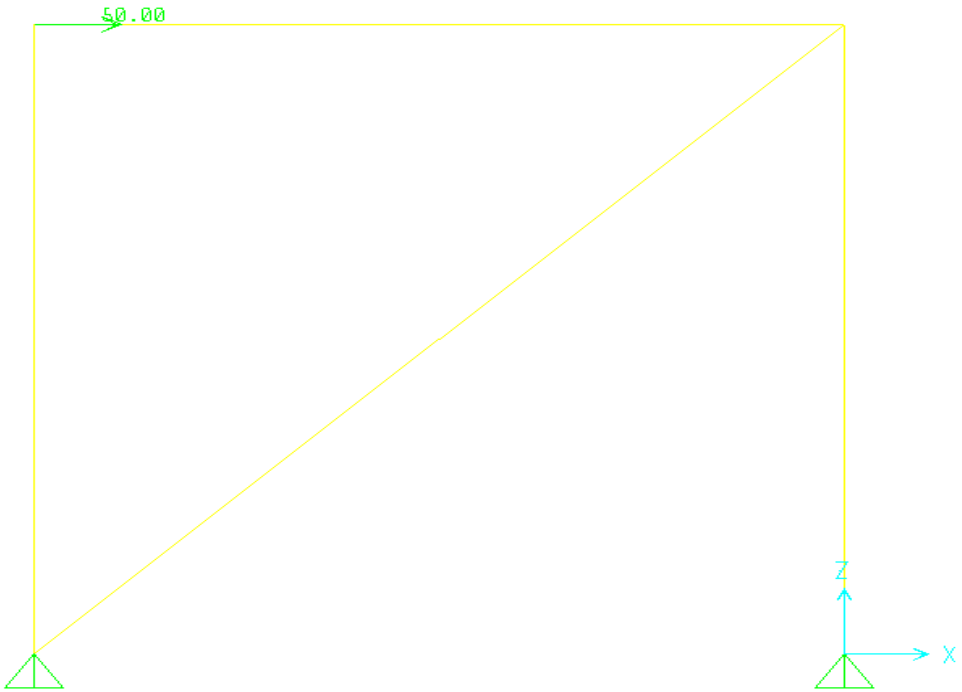
**Ather Ali**

## Description

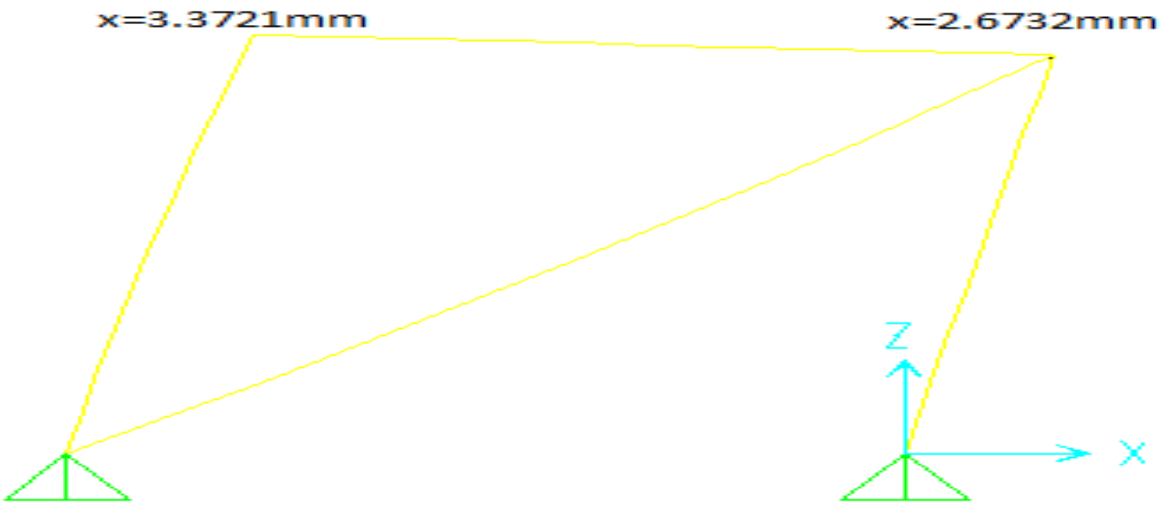
Generally when we talk about bracings we discuss them as tension members used to transfer lateral loads to the foundations. But these bracings also affect the displacement of joints if they are placed at the joint where the load is applied.

## Explanation Using Computer Model

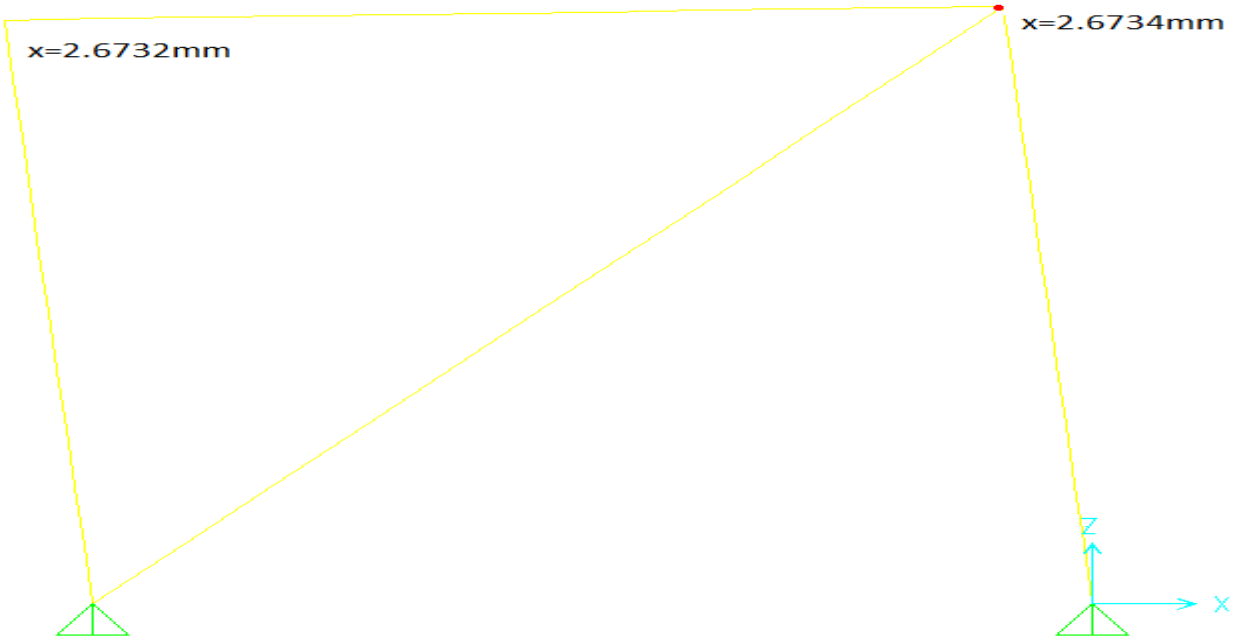
Consider a frame structure with pinned joints and a bracing member provided in one direction as shown below.




A 50KN load is applied as shown above and the displacement of the joints is as follows.



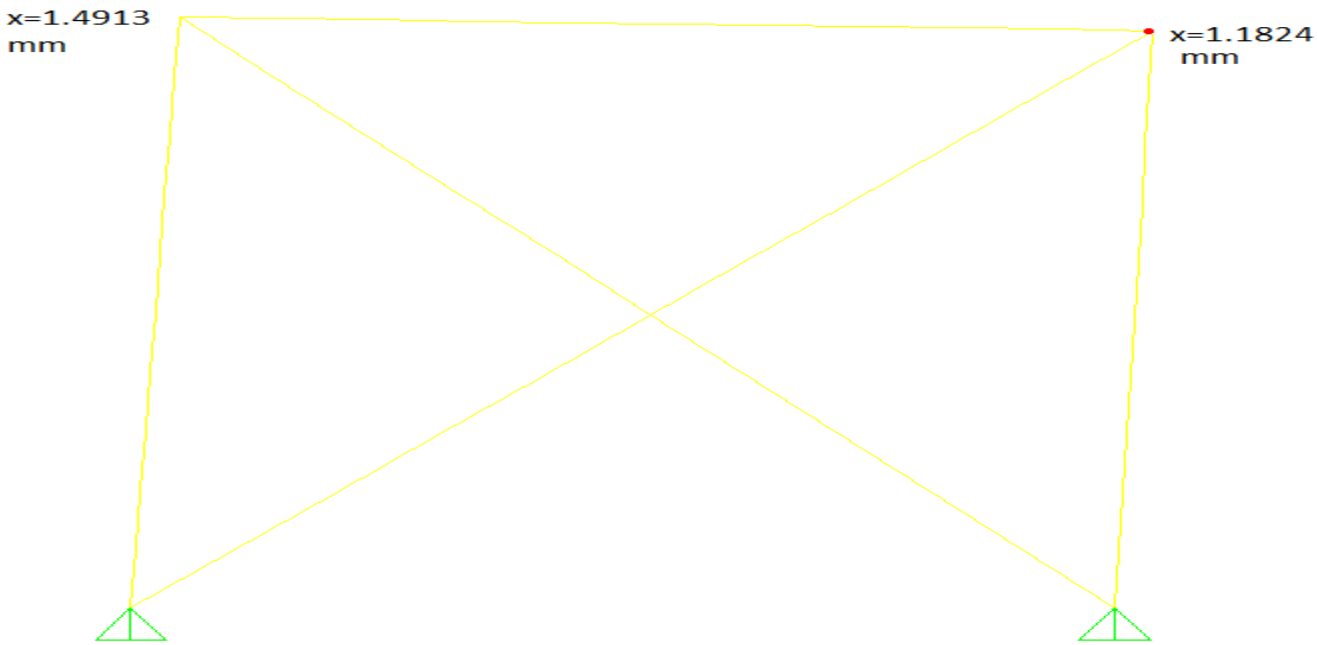

But if the lateral load is applied from the point where the bracing member is connected then the deflection would be as follows.




Thus it is clearly visible that bracing members if provided at the points where lateral loads are supposed to act would help in decreasing the displacement of joints even if they are in compression.

But in reality to economize our design bracing members are designed as tension members so that a lighter section can be used because if bracings are designed as compression members then to prevent buckling we need bigger sections.

However, in reality we provide bracings in both directions but their design is mainly that of a tension member. But if they were to act as tension members as well then the deflection would be as follows.




**Conclusion**

The whole point of my study was to show that apart from being as tension members, rigid bracing members may as well serve the purpose of minimizing the deformation of the structure.

# 1.2 CONCEPT OF DEFLECTION OF BEAMS

**GAUTHAM SATHISH**

**Why is it ideal for the breadth of a rectangular beam to be shorter than or equal to the depth of the beam?**

For a simply supported beam,

$$\text{Deflection, } \delta = \frac{wl^3}{48\,EI}$$

where,

w : load acting on the beam
l : length of the beam
E : modulus of elasticity
I : moment of inertia

In the model,
breadth of the beam : '4 cm'
depth of the beam : '8 cm'

**FIG. 1 LOADING A BEAM BREADTH WISE RESULTS IN LARGER DEFLECTION –**

Consider the loading of the beam breadth wise.

We know, for a rectangular beam cross section, $I = bd^3/12$

where b = breadth and d = depth of the beam (here b = 8cm and d = 4cm)

therefore $I = 42.67\ cm^{4.}$

**FIG. 2 LOADING A BEAM DEPTH WISE RESULTS IN SMALLER DEFLECTION**

Now load the beam depth wise,

$I = bd^3/12$ (here b = 4cm, d = 8cm)

therefore, $I = 170.67\ cm^4$.

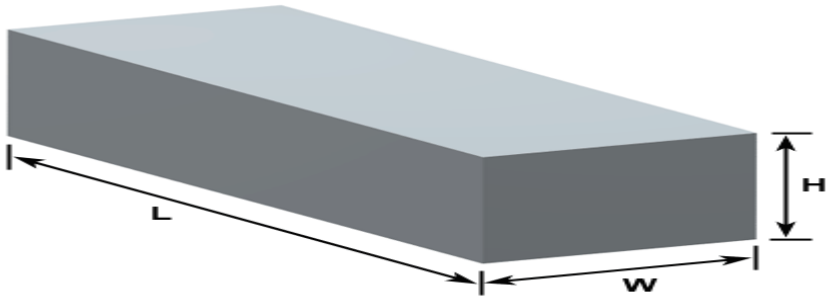
**INFERENCE :**

- In this model w, l, E are kept constant and I is the only variable.
- Clearly when the beam is loaded depth wise 'I' is larger.
- Deflection, $\delta$ is inversely proportional to I. The deflection of a beam under load is inversely proportional with the product of the E-modulus and the moment of inertia of the cross section.
- Therefore the deflection will be larger when the beam is loaded breadth wise as shown in figure.

**THEORY :**

A beam is a structural element that resists loads primarily in bending and shear. It must have adequate strength to resist failure and stiffness to prevent deflection. Strength and stiffness of a beam is influenced much more by the depth than by the width.
The strength of the beam is dependent on the section modulus, Z.
We know from the bending equation,
$f = M/Z$ and $Z = I/y$
where, f : Bending stress
M : Bending moment at the section
Z : Section modulus
I : Moment of inertia at a section
y : distance of the extreme end of fiber from the neutral axis

FIG. 3 A RECTANGULAR BEAM




For a rectangular beam cross section, $I = bd^3/12$,
where b = breadth and d = depth of the beam.
So in order to minimize the bending stress f, we need to provide a beam with a higher Section modulus, Z. Since the moment of inertia I is proportional to cube of depth for a beam, to minimize the stresses acting, it is suitable if depth is higher than breadth. To resist a given bending moment and to keep deflections small, deepest beam is the most suitable. However, if the depth is made too high in proportion to the breadth, the beam may buckle sideways due to a column effect as a result of compressive stresses in the top fibres of the beam.

References :
1. http://www.answers.com
2. http://www.structural101.com/Beam-Design---Basic.html
3. http://www.nilit.com/plastics/technical-support_part-design-02.asp

# 1.3 Equilibrium in your daily workout!

**Georgios Proestos**

**Concept:** **Equilibrium**
**Structure:** **A door pull up bar with no screws**

The concept of equilibrium is vital in our everyday life, from the simple act of walking to the more complicated act of constructing a structure; without equilibrium, any structure would topple and eventually fail.

Definition: A body is in equilibrium if the acceleration of its centre of mass is zero in all directions, and its angular acceleration is zero. In addition, the sum of moments acting on any point of the structure should add up to zero. Therefore, the resultant force R and the resultant couple M are both zero.

Practical Example: A pull up bar with no screws will be demonstrated to show the concept of equilibrium. In a pull up exercise, the body is suspended by extended arms, gripping a fixed bar, and then pulled up until the elbows are bent and the head is higher than the hands, utilizing an overhand grip. So how could a bar with no screws be able to accommodate such an action? The answer lies within the concept of equilibrium.

The pull up bar consist of a durable steel frame and installs quickly with no screws as it uses leverage to hold against the doorway. The bar is illustrated on Figure 1.

*Figure 1*

The bar is then fitted in a doorway, with the leverage lying on top of the door frame and pushing against the wall as illustrated on Figures 2 (a) and (b).

*Figure 2 (a)*

*Figure 2 (b)*

Once a person hangs off the bar, the vertical load from the weight of the person applied at the handle positions is resisted from the vertical reaction force that the leverage makes against the door frame. When the person pulls up himself to make the exercise horizontal forces are induced and these are opposed by the extended handles which are in contact with door frame. Also, a moment is induced due to the handles having a horizontal 'x' distance away from the point of contact of the leverage and the wall, therefore an equal and opposite moment is reacting as the leverage 'pushes' against the wall. The forces are illustrated on Figure 3.

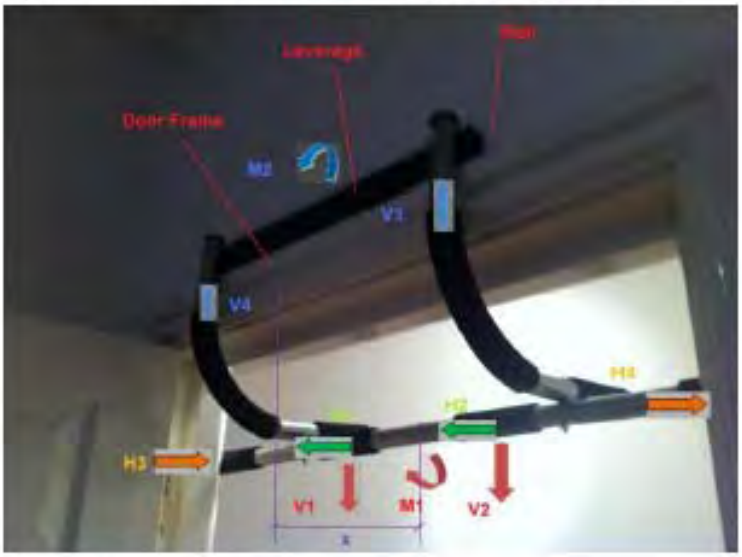



*Figure 3*

In general, ***for any equilibrium to exist***, the following is satisfied:

***Σ(V) = 0; Σ(H) = 0;***
**And about any point in the system: *Σ(M) = 0*;**

Where V = Vertical Forces, H = Horizontal Forces;

In this case and according to Figure 3, the vertical forces caused by the person hanging from the bar (illustrated with red arrows) $V_1$ and $V_2$ are causing the vertical upward reaction forces (illustrated with blue arrows)$V_3$ and $V_4$ to the point of contact of the leverage against the door frame.
Therefore since $\Sigma(V) = 0$ :

$$V_1 + V_2 = V_3 + V_4$$

In addition Horizontal forces H1 and H2 due to the upward movement of the person while doing the 'pull up' exercise, are opposed by the horizontal reactive forces coming from the contact of the extended handles and the door frame.
Therefore since $\Sigma(H) = 0$ :

$$H_1 + H_2 = H_3 + H_4$$

Also a moment $M_1$ (illustrated by the red curly arrow) is induced from the horizontal distance 'x' that exists between the applied vertical and horizontal forces and the leverage-wall contact point. This causes a reaction moment, $M_2$ (illustrated by the blue curly arrow), as the leverage pushes against the wall in order to maintain equilibrium.
Therefore since $\Sigma(M) = 0$:

$$M_1 = (V_1 + V_2 + H_1 + H_2)x = M_2$$

In this way the pull up bar can work without any screws being drilled on the door frame which has been the traditional way of functioning of such a system in the last years. ***A video is also provided, where the practical example is demonstrated.***

## Bibliography

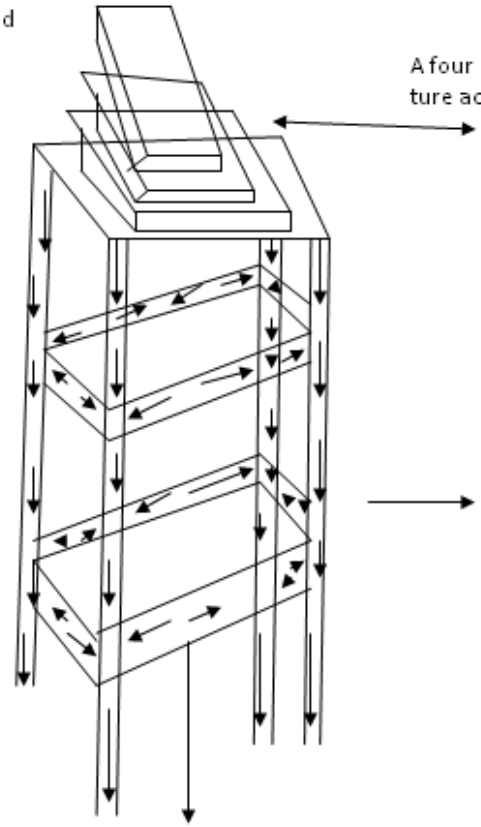
1. Structural Concepts Website: [ http://www.mace.manchester.ac.uk/project/teaching/civil/structuralconcepts/ ]; cited: 22nd October 2010.
2. Photographs taken from home; cited: 22nd October 2010.

# 1.4 Load distribution

**Gitu ikwa Bassey**

A case study of a wooden stool with load of books on top of the stool. See how the load of books are been distributed as load and transmitting the load of books as a vertical load, that is weight of the book from the top of the stool through the bracket down the foot of stool(the stool leg)

Wooden Stool with books acting
As vertical load



Bracket

Fig 1

A four story framed high rise building struc
ture acting as vertical load

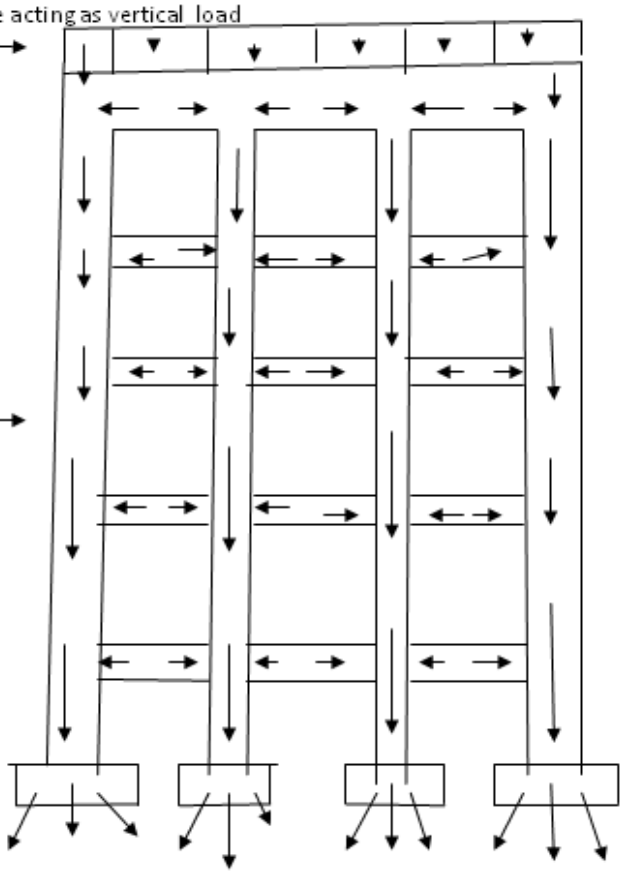


Fig 2

Applying this concepts structurally on a four storey high rise structure as
See in fig 2 in term of load distribution,we can see that the vertical load are
Transmitted from the slab → beam → column → foundation in the
Same channel as in fig 1 of my structural concept transmitting load safely

To the foundation/ground.
The load distributed are indicated with line diagram.
Conclusion : With the diagram in fig 1, showing how loads on a wooden Stool with books on top are distributed as vertical load to the ground . This can be applied practically in simple analysis of load distribution of Framed structure as seen fig 2.

REFERENECE: M S WILLIAMS AND J D Todd for structures theory and analysis 2, WILLIAM M C McKENZIE for Examples in structural analysis

# 1.5 Tension Structures

**Habeene Habeenzu**

A tension or tensile force may be defined as a pulling force and structural elements that transmit loads in tension are called tension members. Structures acting in tension have been used to create numerous stunning and elegant structures.

Fig 1 Hulme Arch Bridge, (Google Earth)

One key advantage that tension members have is that they do not suffer from buckling effects as members in compression do. This means that where as compression members may have to be designed to resist these bending forces from buckling, tension members need only be designed for axial load and hence the entire cross sectional area of a member in tension can be utilised to resist tensile forces. As result of this efficiency in material use is gained and is utilised to design light weight long spanning structures. And this is why tension members usually have smaller cross sectional areas compared to compression members.

(a) (b)

Fig 2 (a) Wire buckles under small compressive load (b) Same wire under tension able to be used to pull mug.

Tension members can be given greater compressive resistance by prestressing them in tension. One example where this is used is the bicycle wheel. The bicycle wheel is "one of the most efficient structural elements in use today." [1] Combining "lightness and exceptional load carrying capacity" [1] it fulfils both function and form.

Fig 3 Pre-tensioned Spokes on bicycle (www.indiamike.com 24/10/2010)

One naturally wonders how heavy loads are carried on thin wires such as those that the spokes of a bicycle wheel are made of. The secret is that the spokes are pre tensioned and this enables them to be able to carry the applied loading by compression at the bottom of the wheel where contact is made with the ground and some of this load is carried in tension by the other spokes. Thus the bicycle wheel actually works by "tension, compression and pre tension." [1] The pre stressing allows the spokes to carry some compressive load without buckling.

Another example and perhaps a more complicated instance of tension and pre tensioning is the spider web. The spider web uses both tension and geometry to derive its strength and is a special type of structure called a tensigrity structure. This remarkably light weight structure "may shed light on our ability to design the next generation of ultra-lightweight, large area space structures." [2]

Fig 4 Spider Web (beembee.com 24/10/2010)

Tension members, together with pre stressing, offer exciting ways to transmit and carry loads. The use of the entire cross section areas to carry loads can be exploited to create light weight structures that can span long distances.

**References**

1. N.J. Salamon and R.A. Oldham, Analysis for Design of Spoked Bicycle wheels, Finite Elements in Analysis and Design 10(1992) 319 -333.

2. Frank K. Ko and Jovan Jovicic, Modeling of Mechanical Properties and Structural Design of Spider Web, Biomacromolecules 2004, 5, 780-785.

# 1.6 Lever Application in claw-hammer

**Hao Guo ( ID: 7715985)**

1. Introduction

An engineer always has to pull out iron nails from the scrap woods in a construction site. Nails can't be extracted using fingers as they stay deep in the wood. In this situation, a claw-hammer helps a lot. Applying lever theory on the hammer, it's a piece of cake to get the nails out with smaller strength.

1.1 claw-hammer

2. Diagram explanation

By the equilibrium of force and lever arm, It should satisfy:

**F1*d1 = F2*d2**;

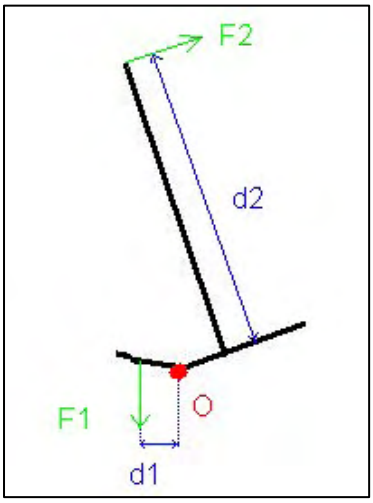
From the equation, **d1** < **d2**, which gives

**F2** < **F1**

And the equation can also be written as

**d2**/ **d1** =**F1**/**F2**.

So the If an engineer want to pull the iron nail out, he just need apply 10% force or less at the end of the handle.




2.1 shows forces and lever arms

3. Further study

Lever theory also be applied in almost everywhere in day life, such as scissors, flask opener, crane. Using lever theory to solve problems may be easier but it may cost more at other stage. In the hammer case, the displacement that **F2** passes would be much longer than the nail goes.

Overall, lever is a brilliant method to solve heavy problems and widely used around us. So why not try to think about giving a fulcrum when you are confused?

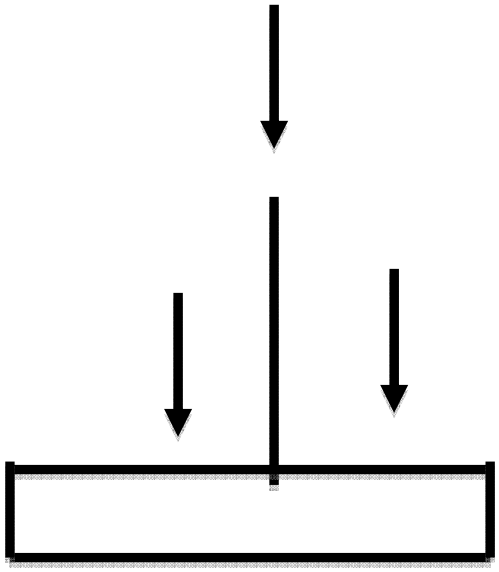
# 1.7 Equilibrium and rotation applied on a vacuum cleaner's head

**ILIAS STYPAS**

The concept of a vacuum cleaner in terms of illustrating the equilibrium state of its head will be examined. As noticed there is member installed axially to the centre of axis of the vacuum cleaner's head as indicated in Figure 1.

Figure 1

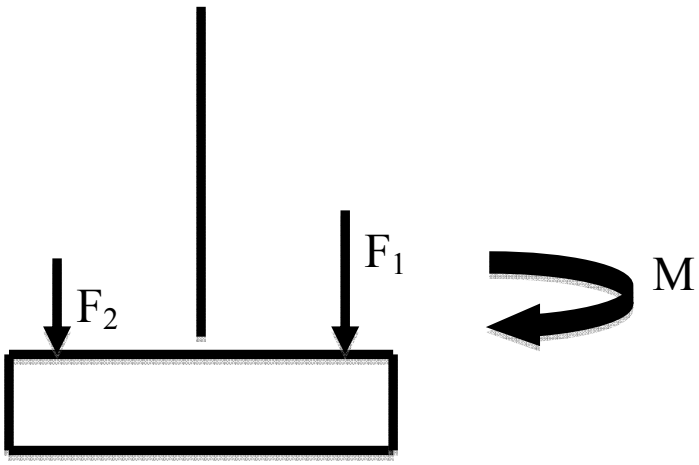
Consider that there was no member in this position and the head would consist of just a rectangular section as shown in Figure 2. In this case when a force is applied to the tube of the vacuum cleaner it will eventually be transmitted to the head. In Figure 3, there is an illustration of an uneven loading, which can take place at the head. In this case the head is no longer in equilibrium. In the case where more force is transmitted in one end as indicated, a moment will be induced and equilibrium will no longer exist. The moment will be $M=F_1xd$.

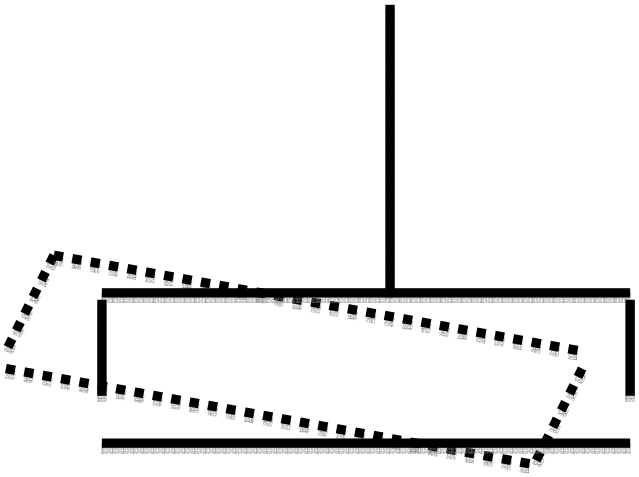


*Applying force to the tube and transferring it to the head*

**Figure 2**

However, in order to avoid inducing moments at the head that would result rotating, a straight element, as shown in Figure 4, could be inserted axially to the neutral axis of the head. This way, the bar will act as a tie bar, which will resist at any uneven loading and will keep the head in equilibrium in order not to rotate and therefore move steadily towards one direction.

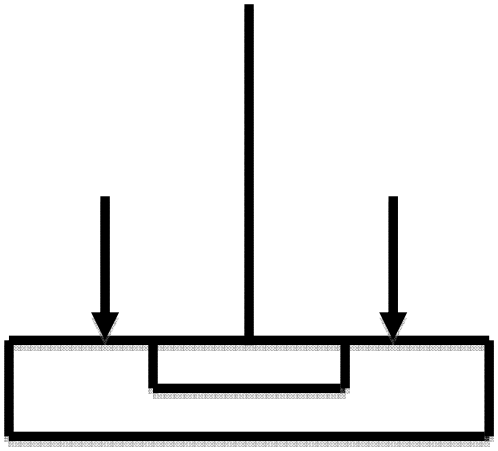




*Uneven force applied to the edges of the head that cause rotation and irregular movement*

**Figure 3**

Therefore, by applying force even greater than before, the additional element will keep the head steady and work as a whole in one direction since the tie is in tension and will keep the edges at the same position.



*Inserting element to act as a tie bar to keep edges steady to movement from force*

**Figure 4**

# 1.8 Span and Deflection

**Jumaane S. C. Paul**

The concept of span and deflection explains the proportionality between the deflection of a flexural member and its span (to the power of three for point loads and to the power of four for uniformly distributed loads) when subjected to loading. It also describes the ways in which the deflection of a flexural member can be effectively reduced:

1) By increasing the depth of the member thereby increasing its structural rigidity and/or
2) Adding supports to the add system thereby improving the stiffness of the member.

These concepts can be attributed to the structural analysis and design of simple foundation elements.

Consider a reinforced concrete pad footing supporting a column and the loads that are attracted to it from a structure. *See diagram 1 below.*

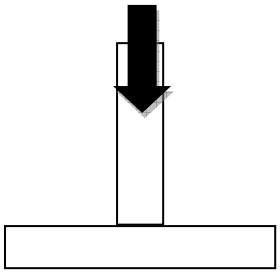


*Diagram 1 - Showing a schematic of a column sitting on an isolated footing, where the loads on this footing are represented by the downward pointing arrow.*

It is common knowledge that all soils compress when loaded, thereby causing the structure to settle. Due to the rigidity of the column and the flexural nature of a footing, the action of the load through the column onto the footing results in the footing deflecting upwards due to the increase in the soil pressure along its base. For all intents and purposes, this scenario can be analysed and designed as an upside down cantilever, where the distributed load is provided by the soil pressure which acts along the base of the isolated pad footing. Although the soil reaction will not be uniformly distributed below the base of the footing in reality, it can be conservatively assumed to be uniform as long as an ideal base area is utilised in the design. *See figure 2 below.*

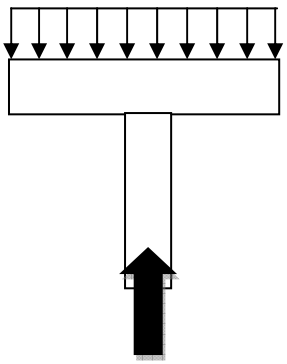


*Diagram 2 - Showing the idealisation of an isolated pad footing supporting a column load for the analysis and design of the foundation member.*

Many times in construction, particularly in highly urbanised city centres, the space allocated for a building site may be almost entirely taken up by the structure itself. This is because the cost of attaining and developing land is extremely high, as such developers and owners are keen to utilise as much of the land area as possible for the structure, thereby increasing their profitability.

For a typical pad footing design, there exists a projection of the pad footing beyond the column line. This project is required for the spreading of the load and varies depending on the actual loads imposed on the column. Because the owner/developer of a one site cannot legally build a foundation across the boundary line, it can be seen that the owner/developer will lose a lot of square area of rentable building space if this type of design is adopted for the exterior columns. Due to stability issues and the harsh realities of differential settlement, the isolated footing cannot simply be slid across the base of the column to satisfy the client's spatial requirements. If this were done throughout a given building, a mechanism would be created which would inevitably result in failure of the foundation and/or the development of undue stresses (which would be manifested by settlement cracks) within the structure.

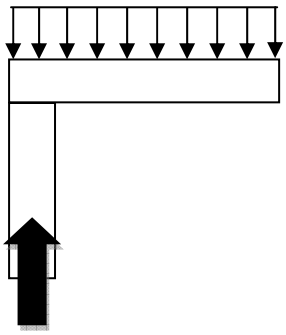


*Diagram 3 - Showing the inherent instability of a column sitting on the end of an isolated pad footing. A mechanism would be created as this system will inevitably undergo severe differential settlement.*

Faced with this problem, engineers have **innovatively** utilised the principles of span and deflection to adequately address this situation, thereby maximising the long term profitability of their clients. If the design of the building is configured in such a way that an interior building column is relatively close to the exterior columns (which is usually the case and not usually an overbearing requirement), one can design a combined footing which mutually supports both the exterior and interior columns. Conceptually speaking, the interior column acts as a "support" for the system shown in diagram 3 above. Such a system is inherently stable since the support provided by the interior column reduces the excess deflection of the footing by shortening its span. *See diagram 4 below.*

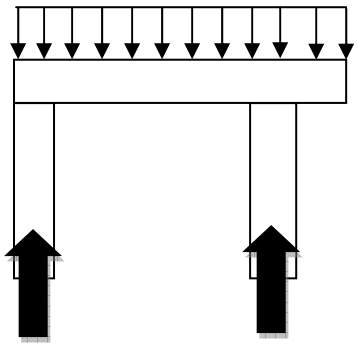


*Diagram 4 - Showing philosophy of span and deflection with respect to the analysis of a combined footing. Due to the spatial restriction on the exterior column, an interior column could be utilised to provide support to the "original" footing.*

This type of footing, a combined footing, is an innovative way by which the principles of span and deflection have been utilised in the structural design of simple foundation elements. It should be noted that whilst the isolated pad footing is idealised as an upside down cantilever, the combined footing must be idealised as an upside down frame element (most times with an overhang beyond the interior column). The "joints" of the frame will not be able to achieve full fixity in reality nor will they act as true pins. Although they will act as partially fixed supports, conservative design dictates that they be analysed and designed as pinned jointed. A typical design of a combined footing element for exterior and interior columns is provided in Attachment 1B.

Generally speaking, one may find that the design for two isolated pad footings may appear to use less material for the combined footing. However it must be remembered that the configuration required for the combined footing (one column sitting at the edge of the footing) is the critical factor. The additional money spent on material and labour will be negligible compared to the long term increased earnings of the owner due to the increased floor area achieved within the structure. Moreover, an obscene amount of steel and concrete would be required to attempt to provide stability for an eccentrically loaded pad footing, as shown in the idealisation of Diagram 3. Ignoring the stability issues with this configuration, any attempt to design such a system to withstand excessive differential settlement would result in exponentially more steel and concrete than both systems (two concentrically loaded pad footings and the combined footing) collectively!

**Reference: The Design of Reinforced Concrete Structures by Hassoun, M. Nadim**

# 1.9 REASON FOR THE COLLAPSE OF WORLD TRADE CENTER

**Kavin Viswanathan**

1. The structural stability of the World Trade Centre depends on the closely spaced columns. Light weight steel truss span are used between the central elevator core and the primary columns on each floor. These trusses will provide support to the concrete slab on each floor and connect the perimeter columns to the core, to prevent the columns from buckling outside.
2. After the crash it destroyed a number of primary columns o several floors of the building and there by weakening the whole system. Initially it is not enough for the complete collapse.
3. Because of the prolonged exposure to fire, the strength of the steel droped, while the elastic modulus of steel reduces, increasing the deflection.
4. The loss of strength of the materials resulted by the fire, combined with initial impact damage have caused failure of the truss system supporting a floor. Failure of the floor system allowed the primary columns to buckle outward.
5. Once there is a collapse in floor, then all floors above would have began to fall. The falling structure will gain momentum and crushing the floors below. The dynamic impact force caused by the huge mass of falling structure landing on the floors below which is higher than the static load they were designed to resist.

# 1.10 Concept: Beam's deflection; Model: The paper beam

**Kyriakoulla Makromalli**

**Objective**

The objective of this model demonstration is to investigate the effect of the Young's Modulus value on a simply supported beam.

**Introduction**

There are several methods to calculate deflection of a beam and one of those methods known as Macaulay's Method (Direct Integration Methods) is explained briefly below:

Equation of bending moment (M): EI v"(x) = M(x)

Equation of slope: EI v'(x) = y'(x)

Equation of deflection (δ): EI v(x) = y(x)

Where,

E is the Young's Modulus

I is the Second Moment of Area of the cross section

EI is the flexural rigidity of the member

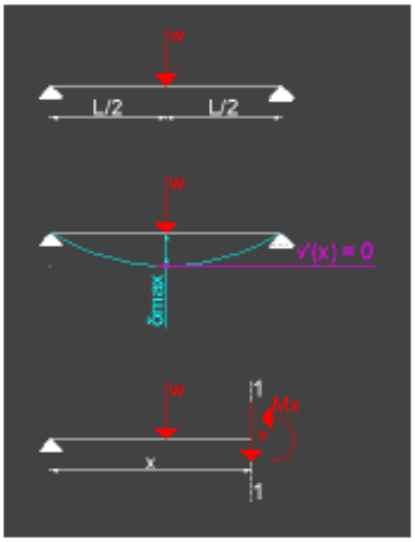



Figure 1: Deflection of a simply supported beam and section 1-1

$\Sigma Fx = 0 \rightarrow + R_{Ax} = 0$

$\Sigma M@A=0$ clockwise, $WL/2 - LR_{By}=0 \Rightarrow \underline{R_{By} = W/2 \uparrow +}$

$\Sigma M@B=0$ clockwise, $-WL/2 + LR_{Ay}=0 \Rightarrow \underline{R_{Ay} = W/2 \uparrow +}$

$\Sigma Fy=0 \uparrow + R_{Ay} + R_{By} - W = 0 \Rightarrow$ **W/2 + W/2 = W** ok

From section 1-1: **M = Wx/2 –W(x-L/2),** equation of moment

***The differential equation of flexure is:*** EI v"(x) = Wx/2 –W(x-L/2)

***Equation of slope:*** $EI\, v'(x) = Wx^2/4 - W(x-L/2)^2/2 + c_1$

***Equation of deflection:*** $EI\, v(x) = Wx^3/12 - W(x-L/2)^3/6 + c_1x + c_2$

*Slope at the centre of symmetrically loaded and supported beam is zero* $\Rightarrow v'(x) = 0$ , $x = L/2$

$EI\, v'(x) = Wx^2/4 - W(x-L/2)^2/2 + c_1 \Rightarrow EI\, 0 = WL^2/16 - W(L/2-L/2)^2/2 + c_1 \Rightarrow \underline{c_1 = -WL^2/16}$

*Deflection of supports is zero* $\Rightarrow x = 0,\ \delta = 0$:

$EI\, v(x) = Wx^3/12 - W(x-L/2)^3/6 + c_1x + c_2 \Rightarrow EI\, 0 = W0^3/12 - W(0-L/2)^3/6 - WL^2\,0/16 + c_2$

$\Rightarrow \underline{c_2 = 0}$

*The maximum deflection is occurred in the centre:* $x = L/2,\ \delta = y_{max}$

$EI\, v(x) = Wx^3/12 - W(x-L/2)^3/6 + c_1x + c_2 \Rightarrow EI\, y_{max} = WL^3/96 - W(L/2-L/2)^3/6 - WL^3/32$

$\Rightarrow EI\, y_{max} = WL^3/96 - 3WL^3/96 \Rightarrow EI\, y_{max} = -WL^3/48 \Rightarrow \mathbf{y_{max} = WL^3/48EI}$

According the formula that was proved above it is seemed that the deflection of a beam depends on the load that will be applied on the beam, the span, the young's modulus value and the second moment of area. Consequently, by increasing the load the deflection is increased as well. But, the aim of the engineer is to design a beam stiff enough in order to resist to the loads that will be applied on the beam. In the following experiment the effect of Young's modulus is investigated by applying same load on two same beams with different Young's Modulus value.

**Experimental Apparatus** (figure 2)

- 2 glasses
- 1 paper beam ($B_1$)
- 1 paper beam reinforced with cello tape ($B_2$)
- 1 mustard bottle
- Ruler
- Sellotape

Figure 2: Apparatus

**Experimental Procedure**

Two beams were made from paper. Both beams had the same dimensions and material properties. The only difference was that one of the beams was reinforced on the bottom with 10 layers of sellotape. The glasses were used for supports and they were placed 30cm away from each other. The paper beam was placed on the top of the glasses so a simple supported beam was constructed (see figure 3a). The bottle of mustard was applied in the middle of $B_1$ and deflection is deformed (see figure 3b). The deflection ($\delta_1$) was noted on the wall (see figure 3d). Afterwards, the bottle of mustard was applied in the middle of $B_2$ keeping the span length same with the previous test and the deflection that was deformed (see figure 3c) was also noted on the wall (see figure 3d).

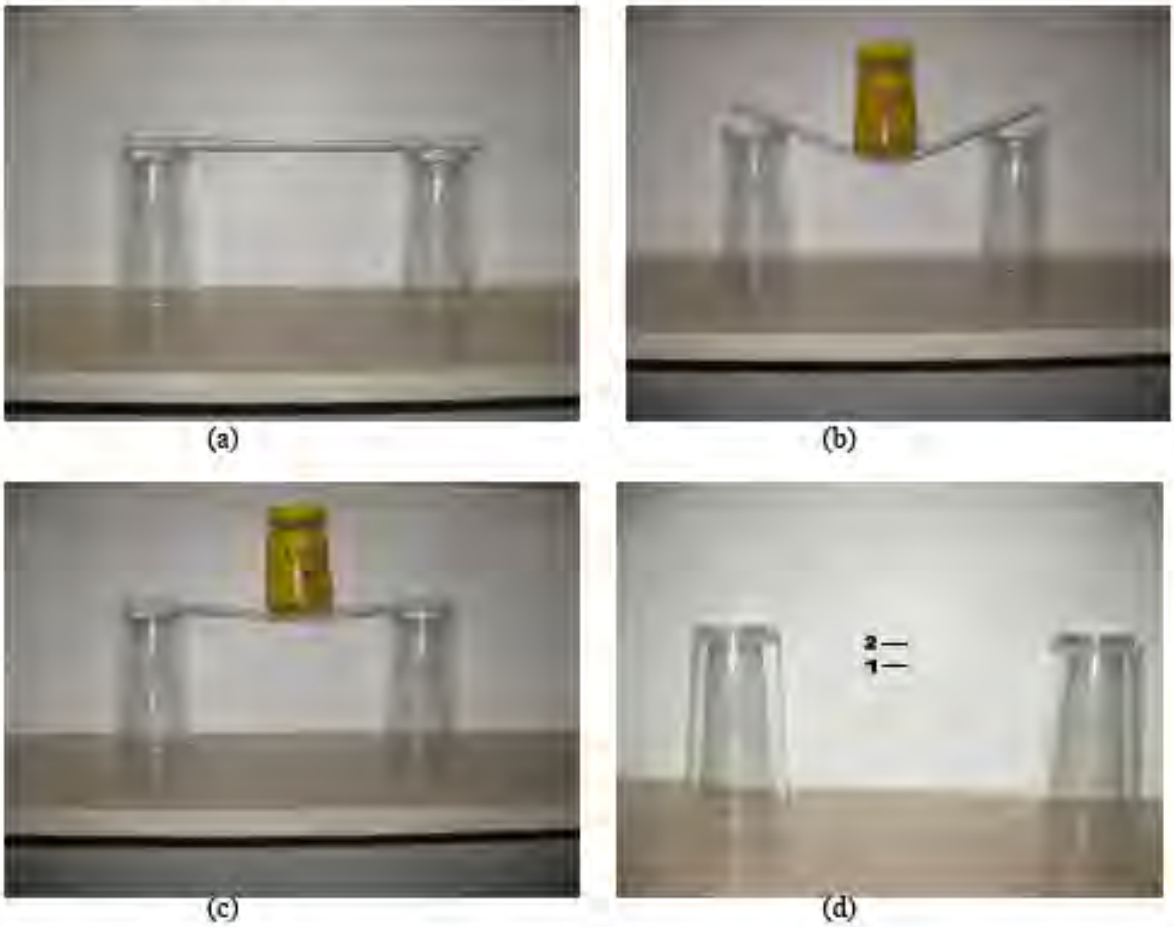



Figure 3: Test procedure

**Results, Theory and Calculations**

| *No. of beam* | *Load (P)* | *Deflection (δ)* |
|---|---|---|
| **$B_1$** | W | 2y |
| **$B_2$** | W | y |

Table 1: Deflection results

$y_{max} = WL^3/48EI$ (below the beam line)

$B_1$: $y_{max} = WL^3/48EI \Rightarrow 2y = WL^3 / 48EI \Rightarrow EI = WL^3 / 96y$

$B_2$: $y_{max} = WL^3/48EI \Rightarrow y = WL^3 / 48EI \Rightarrow EI = WL^3 / 48y$

**Discussion of Results**

Despite the fact that same load was applied in both beams, it was observed from the test that the deflection ($\delta_1$) that was occurred in the middle of B1 was twice more than the deflection ($\delta_2$) that occurred in the middle of $B_2$. The deflection that was caused on the supports (see figure 2b and 2c) is ignored due to the reason that this deflection should be zero by law. It can be observed from the test that $B_2$ flexures less than $B_1$. This is also proved by the calculations. The flexural rigidity of the $B_1$ was found to be 50% lower than the flexural rigidity of $B_2$. Although, 10 layers of sellotape were attached on the bottom of $B_2$ the Second Moment of Area remains equal to the Second Moment of Area of $B_1$ due to the reason that the thickness of the sellotape is extremely small so it can be considered negligible. Thus, the analyst is in the position to say that the reason that $B_2$ deflects less than $B_1$ is because of the Young's modulus value. It is obvious that by reinforcing the paper beam with sellotape the Young's Modulus is increased and that makes the beam stiffer and able to resist in the load and deflects less.

***How is this demonstration of model related to real life?***

In structures where high tensile strength, lightweight fibres and durability are the main concerns Fibre reinforced polymers are applied on the structure in order to reinforce the structure and prevent it from failing. The Fibre reinforced polymers can be applied during the construction of a structure or they can be added on structures originally made of concrete or steel in order to lengthen the existence of the structure. For example, the McKinley Tower was reinforced with Carbon and Glass Fibre Reinforced Polymers because it suffered by lots of damages caused by an earthquake. In the following pictures the McKinley Tower is presented:

(a) (b)

Figure 4: (a) McKinley Tower, (b) Columns in McKinley Tower wrapped with Fibre reinforced polymers (QuakeWrap. (2009) *FRP Retrofit of shear walls in high rise building*. [Online] [Accessed on 23 October 2010] http://www.quakewrap.com/project_sheets/FRP%20Retrofit%20of%20Shear%20Walls%20in%20High%20Rise%20Building.pdf)

**Conclusion**

The above experiment showed that by increasing the Young's Modulus value the beam deflects less. In order to increase the Young's modulus value in real life fibre reinforced polymers can be attached on beams, slaps and columns.

**References**

1. Ji et al, (2008) *Seeing and Touching Structural Concepts*. The University of Manchester. [Online] [Accessed on 18 October 2010] http://www.mace.manchester.ac.uk/project/teaching/civil/structuralconcepts/
2. QuakeWrap. (2009) *FRP Retrofit of shear walls in high rise building*. [Online] [Accessed on 23 October 2010] http://www.quakewrap.com/project_sheets/FRP%20Retrofit%20of%20Shear%20Walls%20in%20High%20Rise%20Building.pdf

# 1.11 The centre mass of the body and why we can jump higher

**Li Yan**

This model demonstrates different result when using two distinct styles in the athletics event of high jump and illustrates why we can jump higher.

Figure 1 Fosbury flop

Figure 2 Scissors-Jump

Figure 1 Fosbury flop
After Fosbury used this Fosbury flop to win the 1968 Olympic gold medal, the technique began to spread around the world, and soon *floppers* were dominating international high jump competitions. Javier Sotomayor (Cuba) is the current men's record holder with a jump of 2.45 metres set in 1993 and is the longest standing record in the history of the men's high jump, of course, using Fosbury flop.

Figure 2 Scissors-Jump
Scissors-Jump ,the most common style used by junior athletes, allow athletes to jump much lower than Fosbury flop.

We all know the world high jump record is constantly refreshed, is it means modern people jumping ability better than what the ancient people?

The answer is no. Scientists found that athletes have almost the same leaping ability, about 1 meter, even if the best high jumper is also not much higher.

But the rule is to require the high jump bar through the body, not necessarily the center of gravity, if I said that many players are jumping drilling under the bar, you must think this is very strange. Of course, it is more accurate to say that the focus of high jumpers underneath the bar, not people .

Let us now answer this question using experiment.

At first we simplify this model :
We divide human body simply into several rectangles with small circles in them, which represents its centre of gravity respectively.

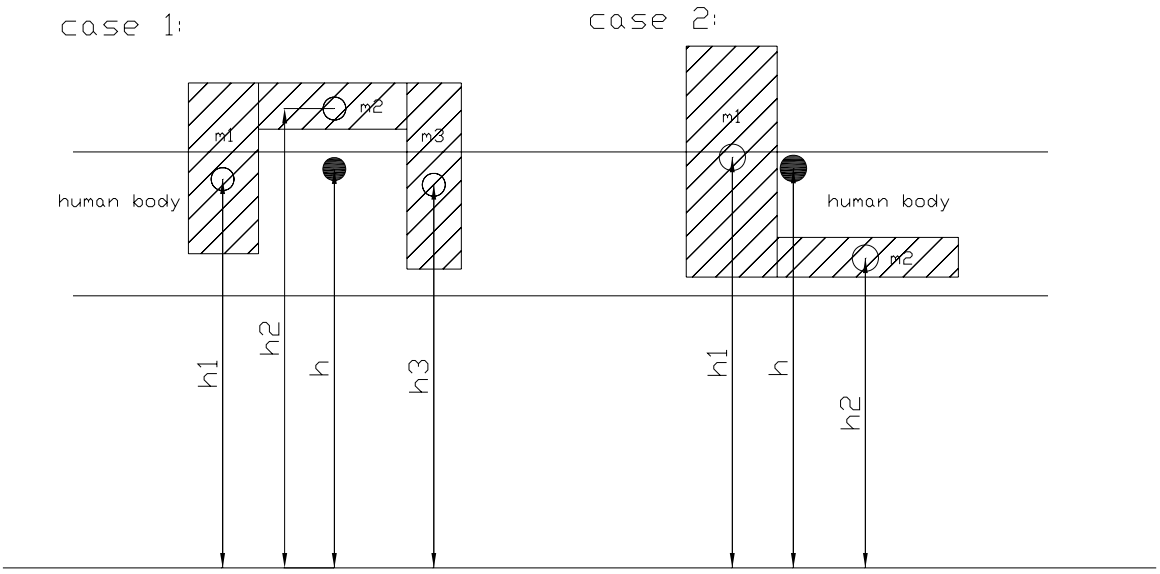



Figure 3

As we all know, the height of centre of mass h is given by usual formula $h = \frac{\sum m_i h_i}{\sum m_i}$, where $h_i$ is the distance from the earth.

In figure 1 , $h = \frac{m_1 \times h_1 + m_2 \times h_2 + m_3 \times h_3}{m_1 + m_2 + m_3}$,

In figure 2 , $h = \frac{m_1 \times h_1 + m_2 \times h_2}{m_1 + m_2}$,

We can see that h in both cases are similar, however, the player in the first case jump much higher than the later one.

Supposing that the height of centre mass of our body is approximately 1 m when we stand on the ground and 2 m when jumping, if we accurately use Fosbury flop, our body center of gravity will be lower about 0.3m, which means we may have the opportunity to jump across 2.3m line. Otherwise, if we use Scissors-Jump, the focus of the body will even be higher. That is , we may lose the chance to jump across 2 metres' bar.

In conclusion, the lower the center of gravity, the better the results of high jump

Reference:
1.Ji, T., Bell, A. (2008). Seeing and touching structural concepts

2.http://www.mace.manchester.ac.uk/project/teaching/civil/structuralconcepts/

3.http://en.wikipedia.org/wiki/High_jump

4.http://image.baidu.com/i?ct=503316480&z=0&tn=baiduimagedetail&word=%CC%F8%B8%DF&in=13611&cl=2&lm=-1&pn=0&rn=1&di=20728829040&ln=1&fr=&ic=0&s=0&se=1&sme=0&tab=&width=&height=&face=0&fb=0#pn6

5.http://image.baidu.com/i?ct=503316480&z=0&tn=baiduimagedetail&word=%CC%F8%B8%DF&in=13611&cl=2&lm=-1&pn=0&rn=1&di=20728829040&ln=1&fr=&ic=0&s=0&se=1&sme=0&tab=&width=&height=&face=0&fb=0#pn1

# 1.12 Studying the Concept of Folder's Compressor Bar

**Mohammed Sadeq**

## Introduction:

We are using folders for organizing our papers almost everyday and using the Compressor Bar to compress those papers to stay fixed to the lower cover of the folder. This compressor bar made by using a structural concept. The structural concept depends on the deflected shape of a very small metal bar and its compression on the main metal ring bars.

Figure 3: Different Shapes of Compression Bars

## What it's made of?

The compressor bar is made of three parts:

1- The Plastic – or metal sometimes – Pushing Arm.

Figure 4: Pushing Arm

2- The two metal bars which are 85-mm length and 1-mm diameter.

Figure 5: Two Metal Bars

3- The Metal Holder which is holding other two parts together.

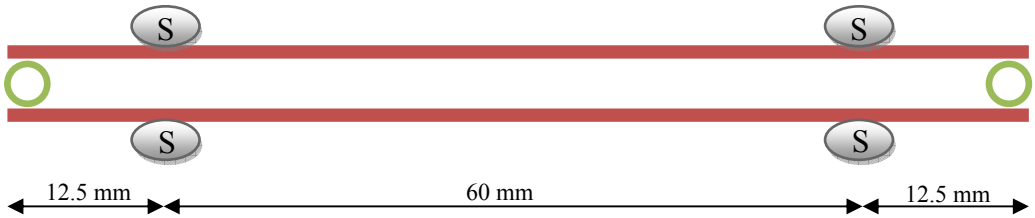
Figure 6: Metal Holder

## The Mechanism of Work:

There are only two cases that this compressor bar can be in; the normal case which has the pushing arm not pushed down and the compressor bar is released to move easily. The other case is that when the pushing arm is pushed down and the compressor bar is fixed and hard to move.

## Simplifying the Idea:

By studying the Metal bar alone and observing the way how it supported, it can be simplified this way:




The Grey Ovals (S) are supports, but roller supports, because it allow the horizontal movement but not the vertical one.
The Red lines are the Metal Bars which are 85-mm length and 1-mm diameter.
The Green Circles are the Metal Rings which are used to hold the papers from the holes made by the Hole Puncher.

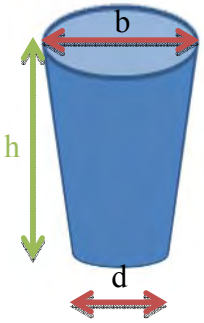
To calculate the enough load needed to push the Pushing Arm down, Glass of Water used by adding water until the class pushed the pushing arm down, as shown in the figures below:

1- The glass of water is placed over the pushing arm.
2- Pouring water starts slowly (to prevent generating force by falling of the water) until the pushing arm is pushed down.

Figure 7: a) Pouring Water Slowly. b) Loaded Water. c) Measuring the Perimeter of the Glass

3- Stop pouring water and measure the volume of the water in the glass and multiply it by the unit weight of the water which is 9.81 kN/m$^3$. (The weight of the glass itself is very small, so we ignored it).

Because the glass has inclined edge, the perimeter is measured in the top and the bottom of the volume of water:




Upper Perimeter = 25 cm = 0.25 m

$0.25 = 2\pi r \; | r = 0.0398\ m$

Lower Perimeter = 21 cm = 0.21 m

$0.21 = 2\pi r \; | r = 0.0334\ m$

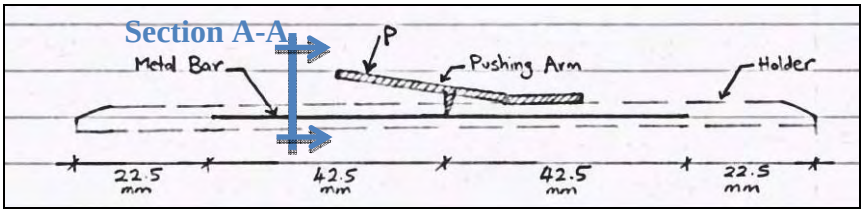
Height of the water = 10.5 cm = 0.105 m

The volume of semi-cone = $\frac{\pi h}{12(a^2 + ab + b^2)}$

Which h is the height of the cone
d is the smaller circle diameter
b is the bigger circle diameter

Volume =
The Load =
This load will be divided by 2 because there are two metal bars supporting the loads.
The load on each Metal Bar = 0.00327 / 2 = 0.00164 kN

When the Pushing Arm is pushed down with enough load to sit the small plastic between the two Metal Bars, it makes a point load in the middle of the metal bar that cause it to deflect down with a certain delta as shown:



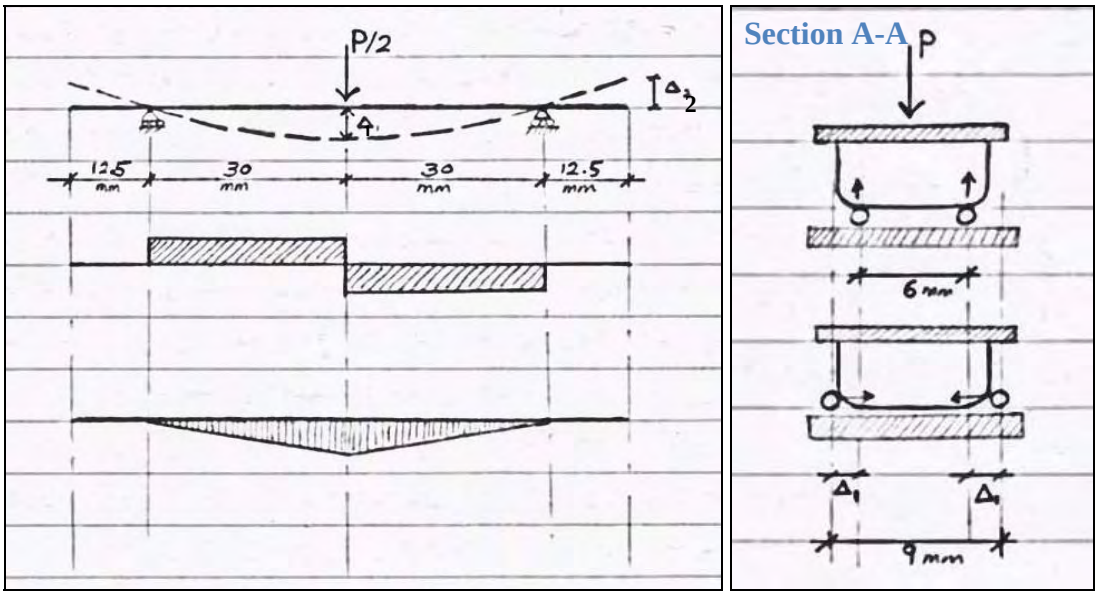




Figure 8: How The Load Affect The Metal Bars

After the load pushed the metal bars apart, the reaction of those bars became horizontal and opposite of each other. Which make them delete each other and keep the pushing arm stays down.

Using a Roller, we measured the deflection for the metal bar and we found it:

$l_1 = 1.5$ mm

$l_2 = 1.0$ mm

# Computer Model:

After calculating the loads required to place the pushing arm down, a Computer Model created to see if the deflection in the real case is same as the computed one by the software. The only problem was that the software wasn't able to model this metal bar because it is too small and loads are very small. So, everything in this experiment is multiplied by 100 as a scale.

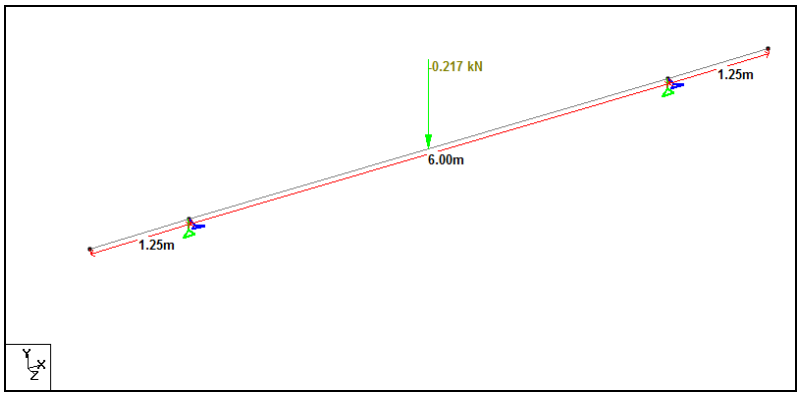



Figure 9: Computer Model (Scaled by 1:100)

The deflected shape for the middle bar between two supports ( ) is: 0.970 mm which is 65% less than the actual result we got from the actual case. Also the deflection in the end of the metal bars

( ) are = 0.606 mm which is 60.6% less than the actual case.

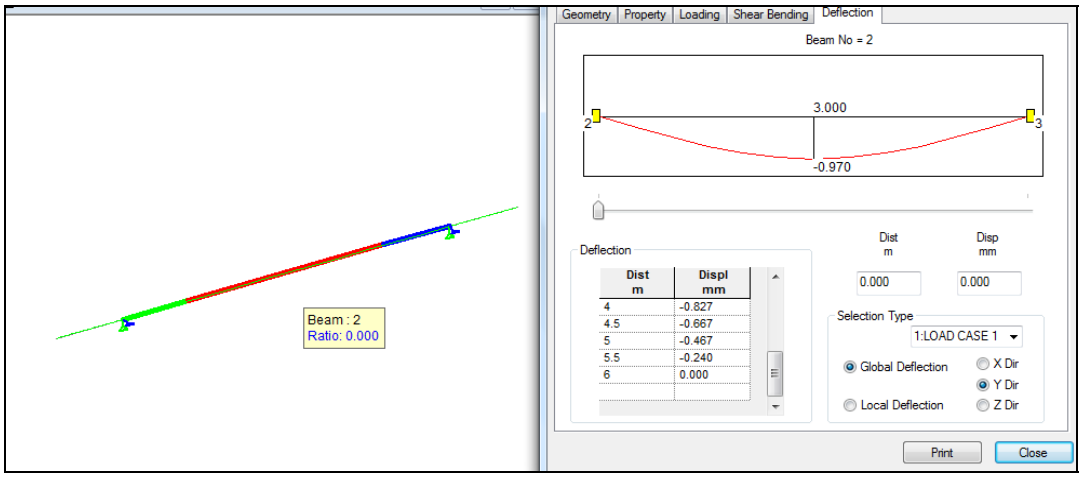



Figure 10: Deflection Shape for the Middle Bar

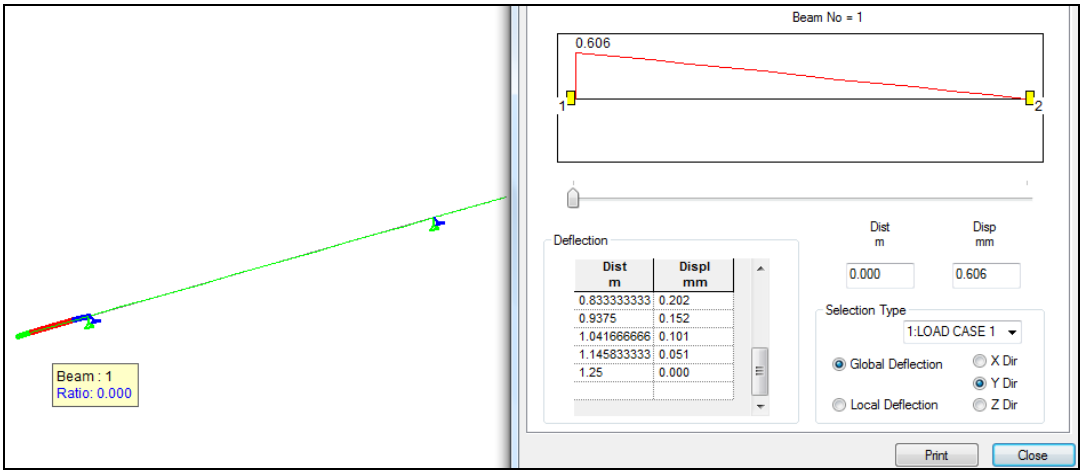



Figure 11: Deflection Shape for the End Bars

# Conclusion:

The deflected shape of this metal bars are pushing at the end of it on the metal ring. And by having two opposite metal bars to each other, we will get the pushing on the metal ring from two directions. This is how the compressor bar is fixed on the metal ring.

The differences happened between the real measurement and the computer software model could happen from those reasons:

1- The Scale we used is very big.
2- Some human error in the actual measurement for the deflection.
3- The Material in the Software for the metal is not same as the actual material.

# 1.13 CANDLE SWING

# CONCEPT OF EQUILIBRIUM AND CENTRE OF MASS

**NEEMA JAYACHANDRAKUMAR**
**STUDENT ID 7685306**

***DEFINITION AND CONCEPT***

**Static equilibrium** can refer to a steady-state situation with no dynamic forces acting on its potential energy in either reverse or forward processes. By definition, in a state of static equilibrium there is balance, but no change, disturbance or movement**. Centre of gravity** of a body is the point through which the whole weight of the body acts. The **centre of mass** is the mean location of all the mass in a system. The location of the centre of gravity of a body coincides with the centre of mass of the body when the dimensions of the body are much smaller than those of the earth. A simple candle swing can illustrate the concepts of equilibrium and centre of mass.

The candle swing work as a simple example of a mechanical system with two equilibrium positions. They are the stable and unstable equilibrium positions. Consider the position of stable equilibrium in the system when force tends the body to go back to original location of equilibrium after displacement. The position of stable equilibrium has minimum potential energy in body of the system. A body is in a state of stable equilibrium when any small movement increases its potential energy so that when released it tends to resume its original position. A body is in a state of unstable equilibrium if, following any small movement, it tends to move away from its original position. In other words, the maximum potential energy of body is present in unstable equilibrium.

***MODEL DEMONSTRATION 1***

**Arrangement**

The candle swing has been arranged as shown in Figure 1 by sticking two similar candles at the two ends of a ruler and then placing the ruler on the middle of a slender bottle.

Figure 1

**Working**

Initially the system is in static equilibrium as the two candles on either side are of the same weight and height. As a result, the ruler stays level. The centre point of the ruler supported on the bottle acts as the 'fulcrum', and this is where the ruler that the candles rest on tilts backwards and forwards. However, because of the state of equilibrium, they remain completely still. Thus the conditions for candle swing to attain equilibrium are: Net force and net torque must be zero. Now first candle is lit followed by the other. As a result there will be an imbalance in the

weights on both sides as the candle starts melting. There will be a lowering of weight on the side where the candle starts melting first. Hence the centre of gravity will shift towards the heavier side and the system will try to regain its position of stable equilibrium. This continues and finally a swing action is introduced in the system. Figure 2 illustrates the action of forces in the candle swing.$F_1$ and $F_2$ represents the varying masses of the candles due to the effect of melting of wax. Clockwise and anti-clockwise moments are introduced at the fulcrum due to these forces, thus unstabilising the state of equilibrium of the system by the introduction of a net force and a net torque.

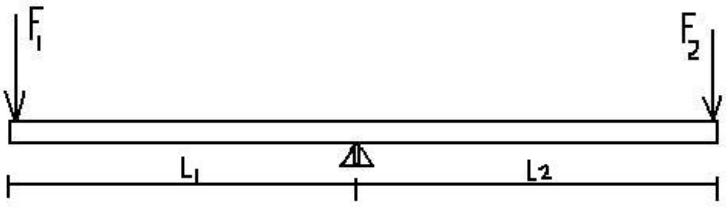



Figure 2

The video shown below clearly illustrates the candle swing action as explained in Model Demonstration 1.

http://www.youtube.com/watch?v=CyvxYzSnZk8

***MODEL DEMONSTRATION 2***

**Arrangement**

The candle swing has been arranged by using a single candle as in Figure 3. It is pivoted at the centre by using a pen's refill. The refill is supported on two Pepsi cans.

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Figure 3

**Working**

Here the candle swing is working on the basis of the same phenomenon as described earlier. Here the point where the candle is pivoted to the refill acts as the fulcrum. When the candle is lit on both ends there will be an imbalance created due to the change in weights as the candle ends start melting. This induces a repeated shifting of the centre of mass of the system and the system while trying to restore its equilibrium will induce a swing action.

The video shown below clearly illustrates the candle swing action as explained in Model Demonstration 2.

http://www.youtube.com/watch?v=hishNORrauE

***CONCLUSION***

From the above demonstrations it can be inferred that the shifting of centre of mass of a system will affect its state of equilibrium. When a net torque or net force gets introduced in the system there will be resultant motion. Thus the static equilibrium condition is altered and the system tries to regain its equilibrium.

***REFERENCE***

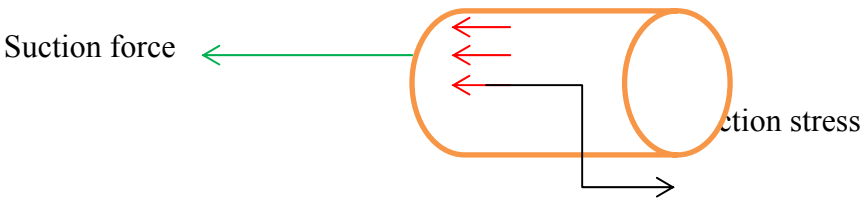
1. www.structuralconcepts.org
2. http://www.technologystudent.com/forcmom/force2.htm
3. Hibbeler, R C, (2005), Mechanics of Materials, Sixth Edition, Prentice-Hall Inc, Singapore, ISBN 0-13-186-638-9.

# 1.14 Research methods course work

PEYMAN AMIRAFSHARI

Opening a wine bottle is always a quite difficult matter to some people, even when they have crock screw in their possision.in this course work a method of using crock screw based on concepts of mechanics of materials has been introduced so that the opening process will become easy.

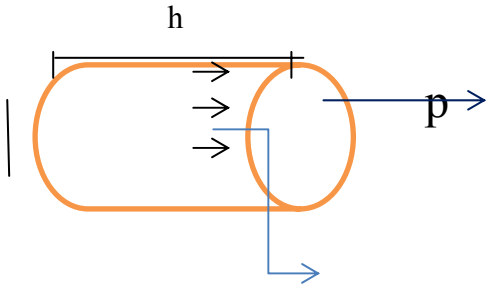
Once a wine bottle of wine is filled with wine a cylindrical crock is derived in to the top of the bottle and the air inside the bottle is pulled out. consequently there are two forces acting on crock that will act against our effort to pull the crock out. Firstly the suction force acting on the inner side of crock and pulls the crock inside, when we try to pull it out and secondly the friction force between the inner side of the bottle and the perimeter of crock. The first one cannot be reduced before taking the crock out but the second one can easily got overcome.




The point is, most of the people screw the wine opener through the crock and then try to pull it out.so the only stress which is imposed to the crock will be direct shear stress that is apparently not enough.

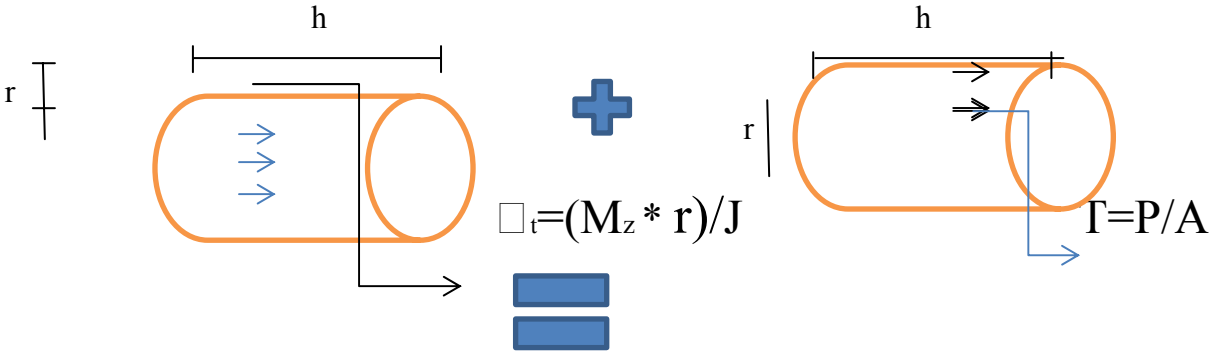
$$T=P/A$$

$$A=h*r*(2\pi)$$

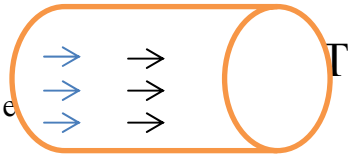



T=P/A

But instead if we will be able to apply another shear stress simultaneously: the resultant shear stress will be maximized. The method suggests that we should first fix the opener to the crock by screwing it through the crock, and then start to pulling it out and at the same time we must twist the crock screw .in this case the shear stress between the inner side of bottle and the perimeter of crock will be the sum of the direct shear stress and the torsional shear stress.




Consequently the bottle opens e



# 1.15 Understanding the Concept of Deflection of Beams for Various Supports

**Rahul Somarajan**

## INTRODUCTION:

A beam member subjected to a load undergoes deformation which we are counting as deflection, when the axis of beam moves in the vertical direction. In other words, the degree to which a beam is displaced under a load is termed as deflection. The deflection can be directly related to the slope of the deflected shape. The deflection of the beam depends on its supports, length, shape, material and the force acting.

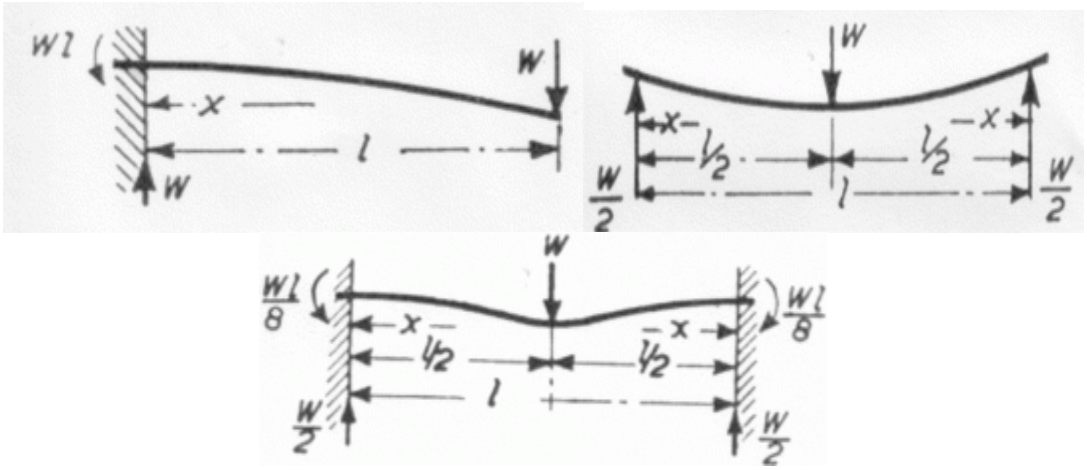



Figure a: deflection of cantilever, simply, supported and fixed beams.

## MODEL DEMONSTRATION:

FIGURE 1: DEFLECTION OF A CANTILEVER BEAM WITH A POINT LOAD AT THE END

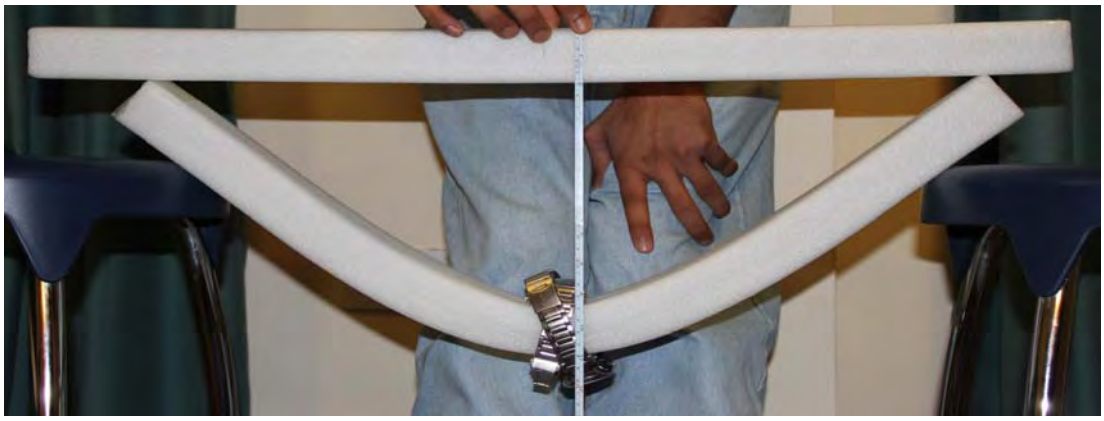


FIGURE 2: DEFLECTION OF A SIMPLY SUPPORTED BEAM WITH A POINT LOAD AT THE CENTRE

FIGURE 3: DEFLECTION OF A BEAM FIXED AT BOTH ENDS WITH A POINT LOAD ACTING AT THE CENTRE

FIGURE 4: DEFLECTION OF AN OVERHANGING BEAM WITH POINT LOAD AT CENTRE

FIGURE 5: DEFLECTION OF AN OVERHANGING BEAM WITH POINT LOADS AT BOTH THE ENDS

FIGURE 6: DEFLECTION OF AN OVERHANGING BEAM WITH POINT LOADS AT BOTH THE ENDS AND AT THE CENTRE

The above pictures shows the deflection diagrams of beams subjected to point loads with various supporting systems like simple, fixed, cantilever and overhanging. In fixed support the beam is rigidly held and the angular deflection at the support is equal to zero. In the simply support, the beam is not held rigidly at the support so it can rotate accordingly with the applied force. Whereas for a cantilever with one end fixed, the slope at the free end where load is applied is maximum, hence maximum deflection. Various numerical methods used for the calculations of deformation of beam deflection are double integration method, moment area method, strain energy method, conjugate beam method and method of super position.

**REFERENCE:**

http://en.wikipedia.org/wiki/Deflection_(engineering)

# 1.16 CONCEPT OF CENTRE OF MASS

**REMIN MATHEW ZACHARIAH**
**STUDENT ID 7684472**

## DEFINITION AND CONCEPT

**Centre of gravity** of a body is the point through which the whole weight of the body acts. A body has only one centre of gravity for all positions of the body.

The **Centre of mass or Mass Centre** is the mean location of all the mass in a system. The location of the centre of gravity of a body coincides with the centre of mass of the body when the dimensions of the body are much smaller than those of the earth.

## MODEL 1

The demonstration shows how the positioning of the centre of gravity of a body helps in attaining stability. The lower the centre of mass of a body, the more stable the body.

### Procedure

Consider the case of an empty box placed on the corner of a table. The box is kept on its corner A. As it is having a very small weight the box can't stand by its own. In this case the centre of gravity falls at the mid section of the box. When the hand support is removed the box will tend to fall down as shown in Figure 1.

Figure 1

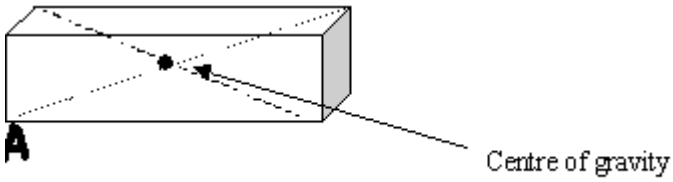



Figure 2

Now place a coffee mug inside the box near its corner A. Now the same box is placed on its corner on the table as the centre of gravity has been shifted inwards and it got lowered. Thus stability has been introduced to the system as seen in Figure.3

Figure 3

In order to explain the behaviour, it must first be understood that initial low mass of the box was increased by adding an internal weight to its bottom end. Thus the ***shifting of the centre of gravity made the system more stable.***

The following video clip shows the entire demonstration.

http://www.youtube.com/watch?v=dhVeq-TDSic *****

(***** The video of the demonstration has been uploaded in YouTube for better understanding of the concept.)

**MODEL 2**

If the centre of mass of a body is not positioned above the area over which it is supported, the body will topple over.

**Procedure**

In the following experiment as shown in figure 4, a one pound coin is placed over a twenty pound note. As the centre of mass of the two bodies pass through the same vertical line the body is in equilibrium and the coin, though heavier than the note, is remaining intact. But if there is a small change in the positioning of the coin or note then the whole system will collapse.

Figure 4

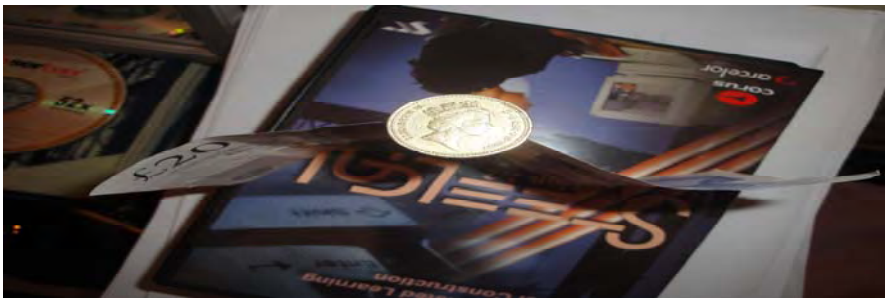


Figure 5

## CONCLUSION

The above two demonstrations clearly illustrate the following two facts.

- If the centre of mass of a body is not positioned above the area over which it is supported, the body will topple over.
- The lower the centre of mass of a body, the more stable the body.

## REFERENCE

1. www.structuralconcepts.org
2. http://www.technologystudent.com/forcmom/cengrav1.html
3. R K Bansal: Strength of materials,(2007) Laxmi publication (P)LTD

# 1.17 Demonstration of importance of Centre of Gravity while freezing in a dance (Head Hollow Back Freeze)

**ROHIT ROY**

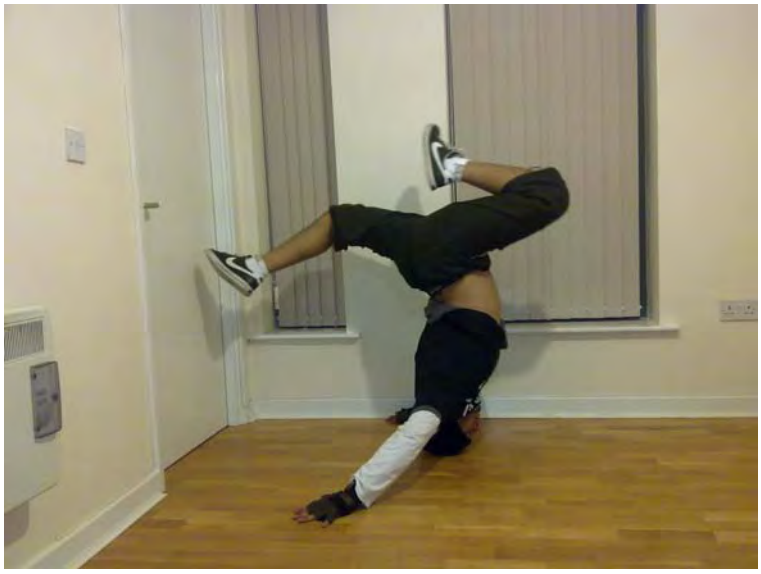


Fig: 1.1

The above figure (Fig: 1.1) illustrates a Head Hollow Back Freeze which is a common Freeze used in Hip Hop Dance Routines. Such a kind of freeze or any such dance freezes can be achieved by the knowledge of Centre of Gravity and Stability.

Fig: 1.2(a)

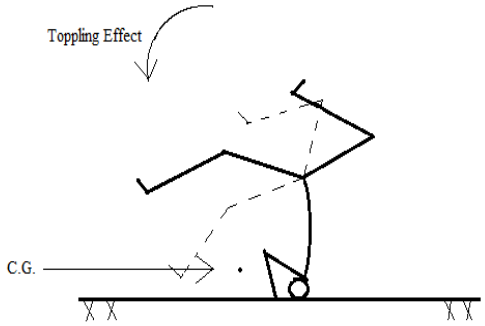



Fig: 1.2(b)

Fig: 1.2(a) shows us an attempt to perform the Head Hollow Back Freeze that turns out to be a failure. This is because when we keep our arms too close to our head, the centre of gravity of our entire body system falls outside the supports of our arms (Head-Arms-Hands system forms the effective support system). This results in an unstable equilibrium as the Centre of Gravity of the body system lies outside the area over which it is supported. As a result of this, the body system topples over because the body cannot be balanced in that position. (See Fig: 1.2(b))

Fig: 1.3(a)

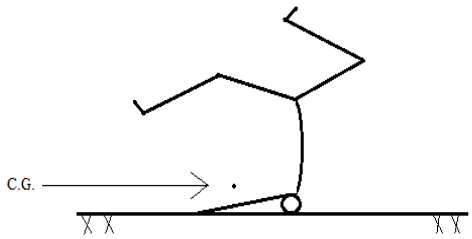



Fig: 1.3(b)

Fig: 1.3(b) shows us a successful attempt to perform a Head Hollow Back Freeze. When the arms are stretched beyond the head the effective support area (Head-Arms-Hands system) increases. Hence, in this case the Centre of Gravity lies directly above and within the area of support (See Fig: 1.3(b)). This leads to the development of a stable equilibrium condition as the mass of the entire body system passes through the area of support formed by the two hands (palms), two arms and the head. As a result of this, the body system can be balanced without toppling over.

Note: Any change in body postures might lead to the change in mass distribution which might in turn change the centre of gravity. This might lead to toppling as the centre of gravity might have shifted and might not necessarily lie above the area over which the body system is supported.

# 1.18 Understanding the Tension force and Tension Structure through the clothesline

**Sen ma**

When a clothesline is tied up each end of the tree, it will be pulled tight by the tension force, which acts on the opposite end of the clothesline. There is an equal pulling force and tension force acting on both ends of the clothesline. In construction field, cables, wires, support columns and beam are frequently used to provide tension force which support reinforces bridges and buildings.

For example:

1. When laundries are hanged up on the clothesline, the self-weight of the clothesline and the weight of the laundries will shaped the clothesline into a smooth downward bow. See figure 1

Figure 1

2.If there is wind, the shape of the clothesline will than changed as it flapping up and down, the stabilizing tensile force is lost. See figure 2

Figure 2

3.Then the clothesline gets to a new tight. See figure 3

Figure 3

4.This problem can be solved by adding a reversed cable on top, and stabilize it by anchored the cable back to the tree. This can avoid the structure flip sideways or invert. See figure 4

figure 4

Moreover, this is a two-way cable net structure and it has a property, in the intersection point between the two cables, they are bent into opposite direction, which is pulling upward and downward, and produce a pressure against each other. If the cable is put into tension, it increases the internal tension. In conclusion, the higher the initial tensions, or pre-stress level, the more stable and stiff the cable net system. See figure 5

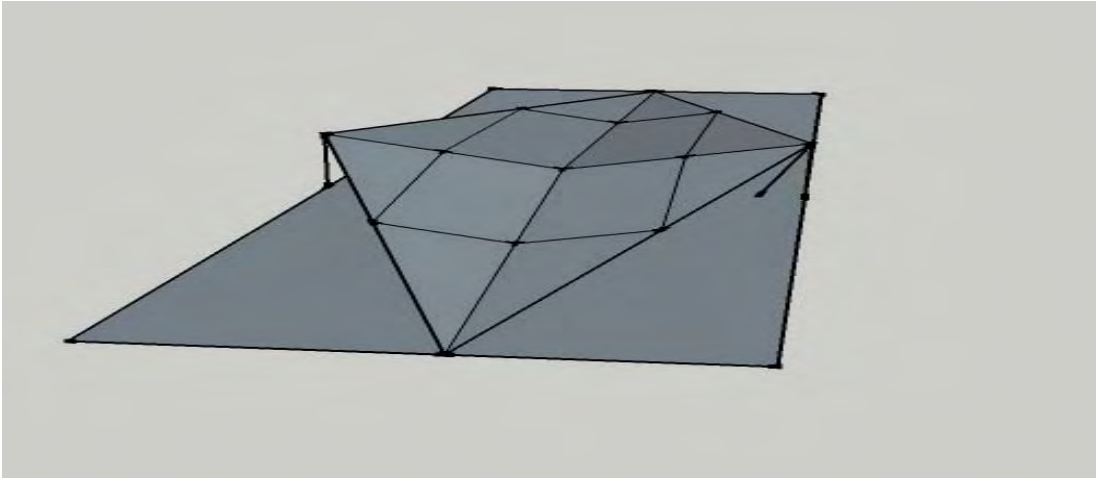


Figure 5

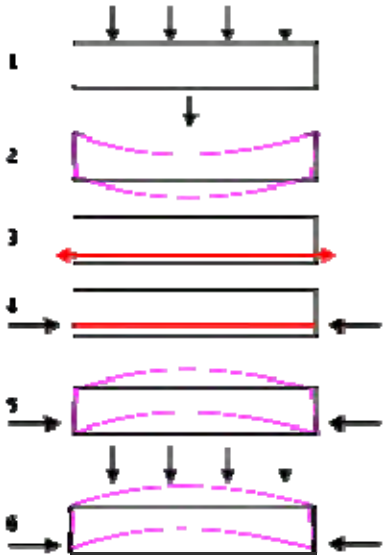
Reference: *Understanding Structures* Derek Seward 3rd Edition

# 1.19 CONCEPTS OF PRE-STRESSED CONCRETE BEAMS

**SHAMANTH BETTAHALSUR MAHESH**

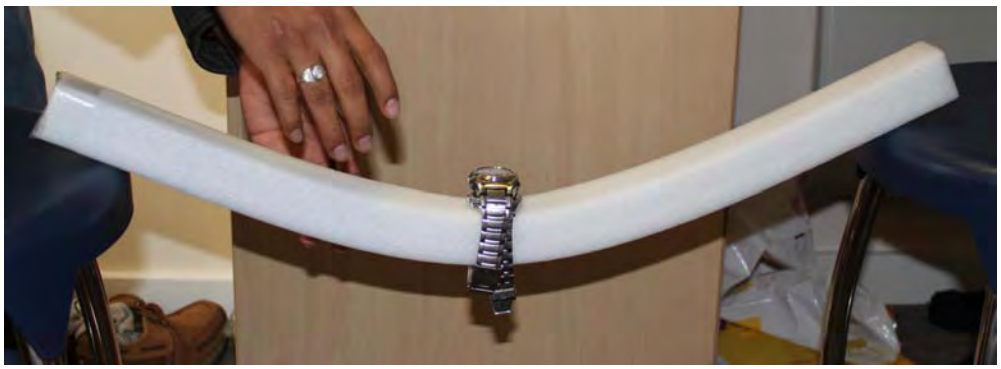
## INTRODUCTION:-

Pre-stressed concrete is concrete in which some stresses are induced to increase the tensile force, to overcome the weakness of concrete in tension. This aids the concrete to be used for the large span beams, bridges, to withstand more loads compared to the normal concrete beams. The way concrete is pre-stressed is by stretching the steel bars or wires called tendons and anchoring them to concrete. When a load is applied the concrete tries to regain its initial length, the pre-stressing tendons resists this and hence pre-stressing occurs.




The above figure explains the behaviour of a normal concrete beam and pre-stressed concrete beam

## MODEL DEMONSTRATION:

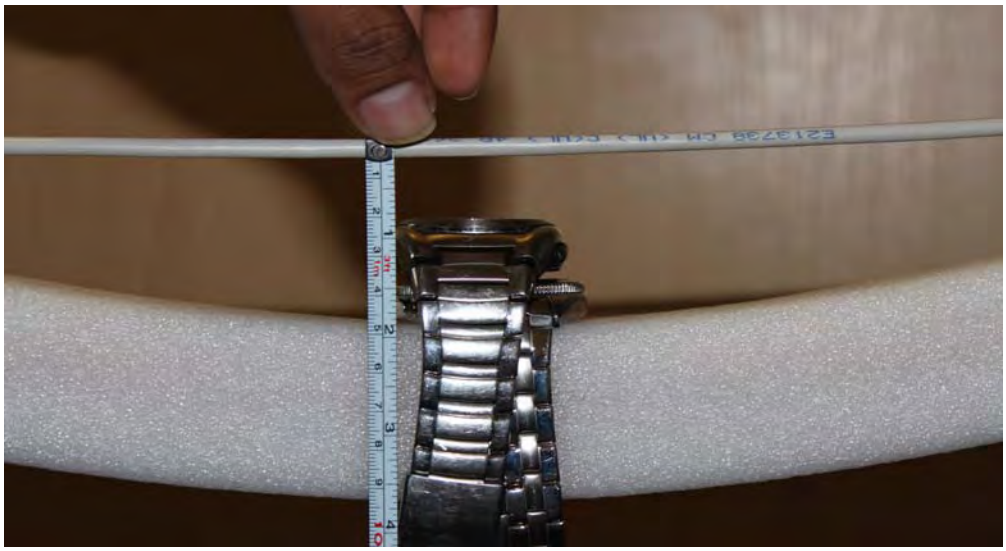


PICTURE 1: A NORMAL BEAM WITH A POINT LOAD AT CENTRE

PICTURE 2: DEFLECTION OF NORMAL BEAM UNDER LOADING (15.6 CM)

PICTURE 3: PRE-STRESSED BEAM WITHOUT LOAD

PICTURE 4: PRE-STRESSED BEAM SUBJECTED TO POINT LOAD



PICTURE 5: DEFLECTION OF PRE-STRESSED BEAM UNDER LOADING (5 CM)

The model above shown demonstrates the difference in deflection between the normal beam and the pre-stressed beam. In pre-stressed beam the tension in the bottom of the beam is reduced aiding the beam to withstand more loads. As from the above demonstrations it is clearly visible that pre-stressed beam can take more loads, and hence the deflection is less compared to the normal beam with same loading. The deflection for the normal beam is 15.5 cm and when the beam is pre-stressed the deflection is reduced to 5 cm for the same loading pattern and for the same material properties.

**CONCLUSION:**

Pre-stressed concrete due to its high load carrying capacity and good resistance to deflection is used for long span beams and bridges where very heavy loads are acting.

**REFRENCES:**

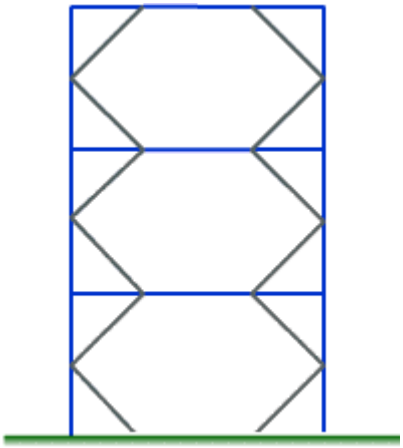
http://www.answers.com/topic/prestressed-concrete
http://www.youtube.com/watch?v=03Hb9VCoEUo&feature=related

# 1.20 BRACED FRAMES- X BRACING AND K-BRACING

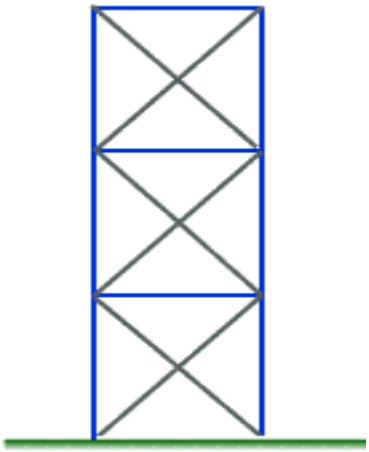
**SHAN PAPPY THOMAS**

## INTRODUCTON TO BRACING:

Building not only experience gravity loads, wind loads, seismic loads and horizontal loads (lateral) are the major concerns. The concept of bracing is to reduce the lateral loads (forces) on the building by transferring the lateral loads into the exterior columns and then to the foundation. Without lateral bracing a structure may fall over under horizontal loading. Normally braced frames are formed by inserting a diagonal structural member into rectangular areas of a structural frame. This stabilises the frame from its side way movements due to the lateral loads. In multi-storied and higher storied, bracing are provided in each and every floors. Normally steel cables are used for bracing as they can be stretched but not squashed.

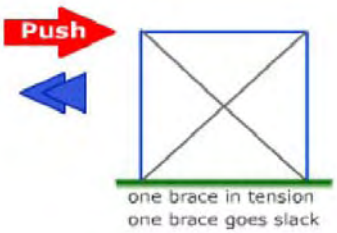


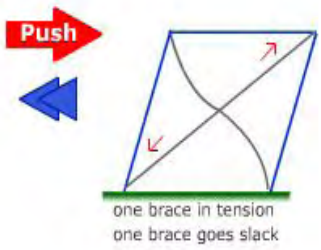
K-BRACING

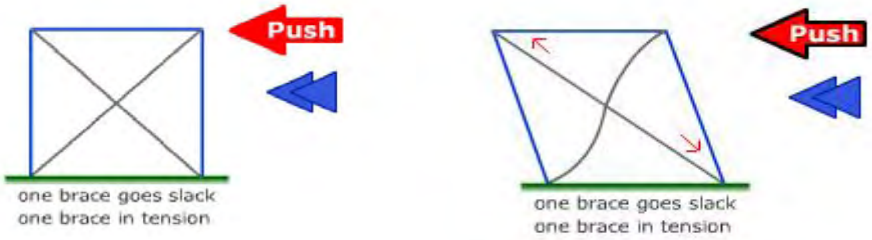


X-BRACING

## DEFLECTION OF X-BRACING UNDER LATERAL LOAD

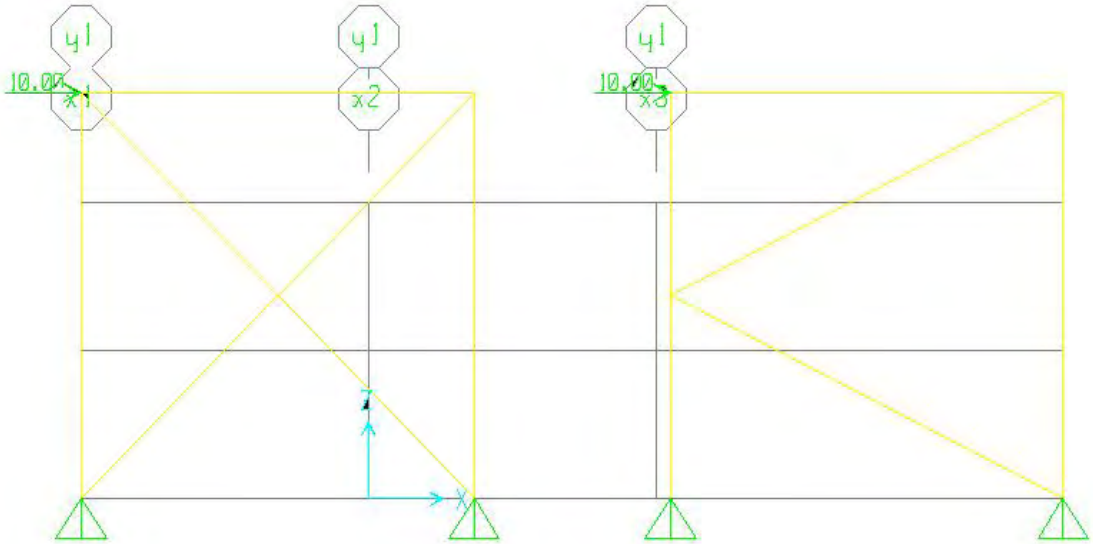


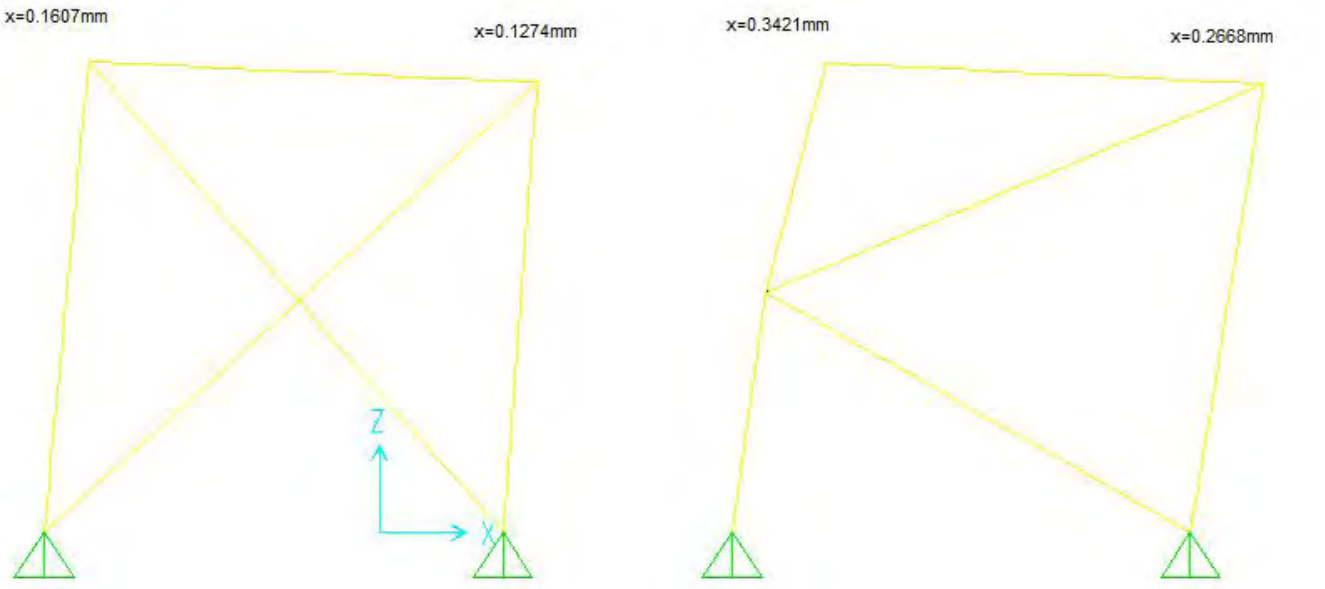



In cross bracing two diagonals are used and their objective is to resist tension. When a lateral load is applied on one part of the frame one of the brace takes up the tension and other takes up the tension when the force is reversed.

**MODEL EXPLANATION USING SAP**




Considering two frames one with x-bracing and one with k-bracing with 10KN load applied laterally as shown above. On running the analysis we get the deflection diagrams for the applied load as shown below.




Deflection of frames given by SAP2000 analysis

According to the above deflection diagrams given by SAP analysis it is clearly evident that X-bracing are far more effective compared to the K-bracing. As when a load of 10 KN is applied laterally to the X-braced frame the deflection values come to about x=0.1607mm where the load is applied and a deflection of x=0.1274mm at the opposite end, whereas for K-braced frame the deflection values are x=0.3421mm where it is loaded and x=0.2668mm at the other end.

## CONCLUSION

The aim of the study was to campare the X-bracing to the K-bracing and came to the conclusion that X-bracing provides more stability than that of K-bracing against lateral loads.

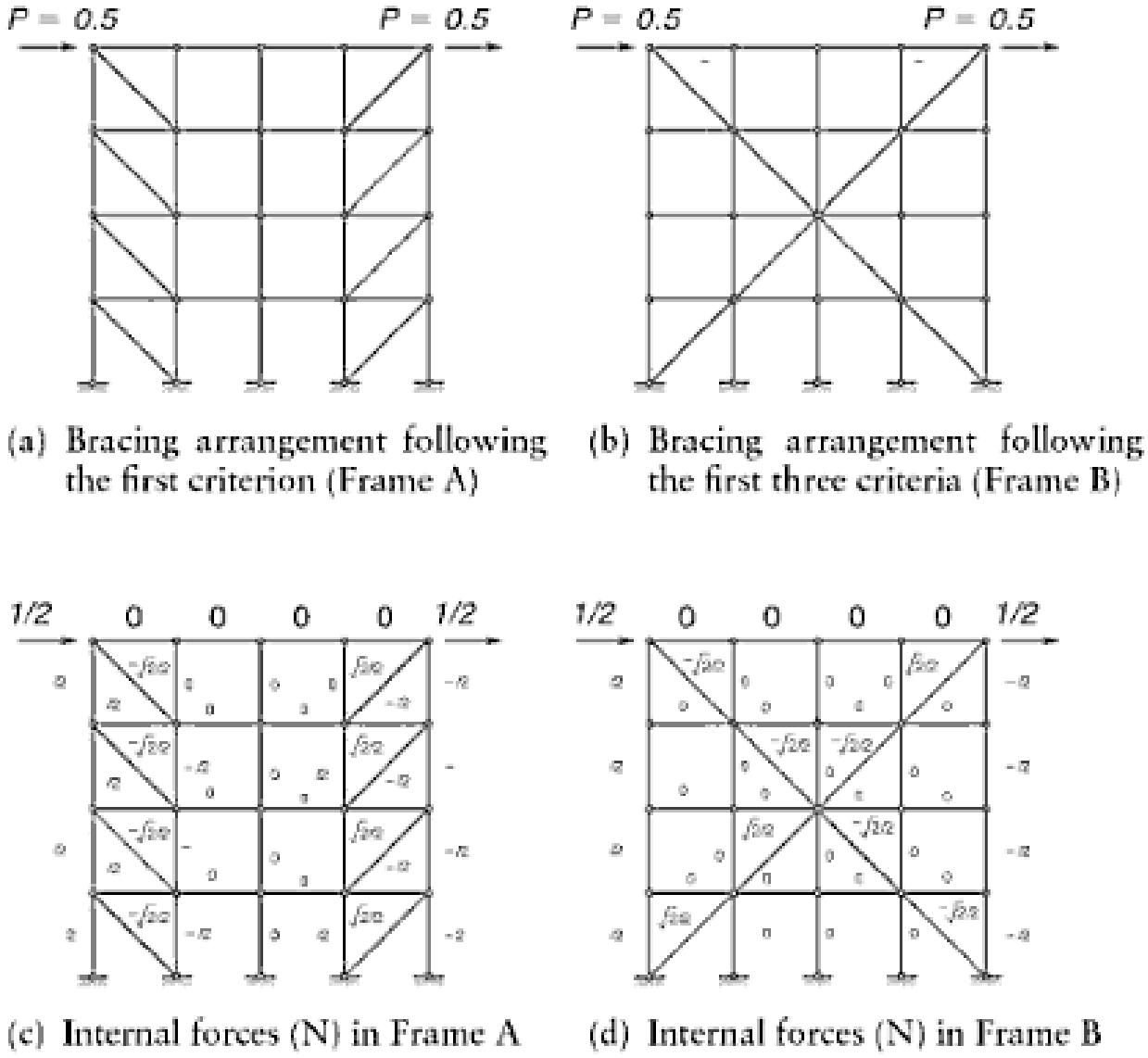
## REFERENCES:

http://www.ideers.bris.ac.uk/resistant/strength_brace.html

http://www.youtube.com/watch?v=4vtkr9UHP1I

# 1.21 Structural Concept

**Siyuan Chen**




(a) Bracing arrangement following the first criterion (Frame A)

(b) Bracing arrangement following the first three criteria (Frame B)

(c) Internal forces (N) in Frame A

(d) Internal forces (N) in Frame B

**Two plane frames with different bracing systems**

The two structures are statically indeterminate. However, they are both symmetric structures subjected to anti-symmetric loads. According to the concept that a symmetric structure subjected to anti-symmetric loading will result in only anti-symmetric internal forces, the internal forces in the two frames can be directly calculated using the equilibrium conditions at the pin joints using the left half of the frames. For example, the internal forces in the second and third horizontal bays of frame A must be zero. In addition, the

forces in the two bays must be anti-symmetric and must be in equilibrium at the nodes on the central column. Thus all the internal forces of the two frames are marked directly in figures c and d, where the positive values mean that in tension and the negative values mean that in compression.

# 1.22 Concept: Statics – Equilibrium Model: Stability of Tower Crane

## Vasiliki Giorgatsou (7679444)

### Introduction

Equilibrium characterises a state of being equally balanced. A body is in static equilibrium when it is at rest and all the forces ($\Sigma Fx=0$, $\Sigma Fy=0$) acting on it cancel one another. Also all the moments ($\Sigma M=0$) acting about any point of the body give zero result. There are many examples in real life that can be explained using the definition of static equilibrium. One of the examples that can be explained using structural concepts is the stability of the tower crane.

### Tower Crane's Stability

Tower Crane is frequently used at remarkable construction sites. It is used to lift construction materials like steel, concrete and mechanical equipment. Often it riches an average height of fifty meters. A tower crane is consisted of the following parts (figure 1):

- The large concrete base on which the crane's base is bolted
- The tower which gives the height of the crane
- The slewing unit which is connected to the tower and permits crane's rotation
- The jib which is connected to the slewing unit
- The motorized trolley which allows the load to move along the jib
- The counter-jib
- The counterweights which give crane's stability
- The operator's cab

In order to stay upright and not fall over it must be well fixed to the ground and manage to balance the load at the two arms (to be in static equilibrium). Maximum load that the crane will lift is calculated in order to put the right weight of concrete counterweights. Regarding to figure 1 it implies:

| Load W x Distance Y = Load of concrete counterweights x Distance X |
|---|

That is the safest condition that must exist to avoid overturning. From the above equation it implies that heavy loads must be carried in a short distance from the tower and light weights in long distance from the tower. For example, the moment that counterweights produce is 200 ton-meters. The load lifted must be either 10 ton x 20 meters distance or 5ton x 40 meters distance or any other combination can exist according to the length of jib. So the moment produced from the lifted load will be balanced by the counterweight.

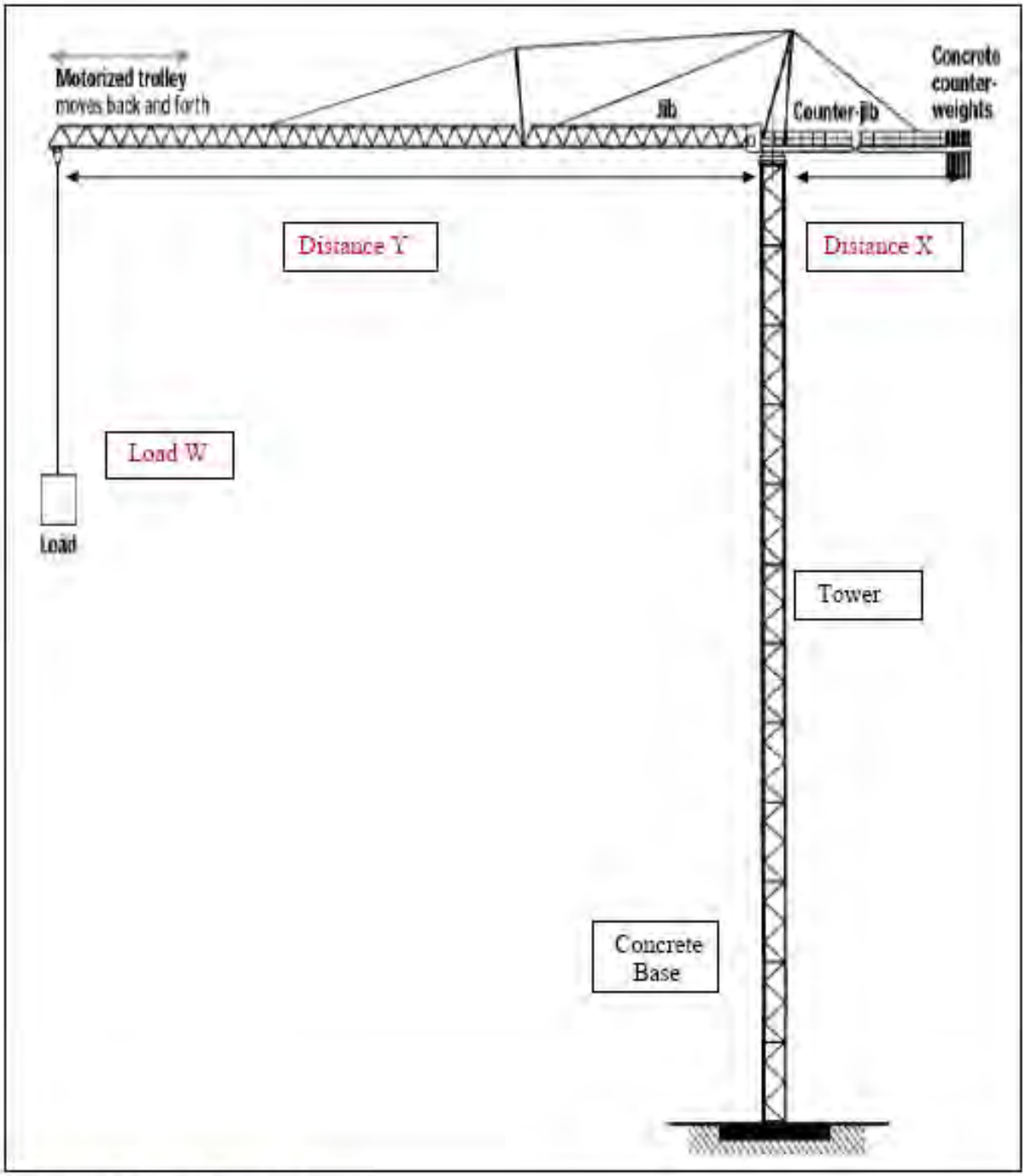



*Figure 1: Tower Crane [1]*

## Physical Model

The following photos show the crane's physical model which is presenting the above theory about static equilibrium of tower cranes.

The materials that were used in this experiment are:

- A paper box
- Sellotape
- Foil
- Yarn
- Light weight decorating object
- Heavy weight plastic box

## Experiment procedure

Crane's model was constructed with paper box and enfolded with foil as it seems in the next photos. A light and a heavy weight material were pointed in different places along the jib in order to examine model's stability. The places which were examined are one far from the support and one near the support. The model's stability is regarding to the following pictures.

## Light Weight Load

*Figure 1: Static Equilibrium*

*Figure 2: Unstable Static Equilibrium – Crane overturned*

**Heavy Weight Load**

*Figure 3: Static Equilibrium*

*Figure 4: Unstable Static Equilibrium – Crane overturned*

**Experiment's Results**

The model is fixed on its base and its horizontal jib is simply supported on the vertical tower. In separate cases light and heavy load is applied both near and far from the support (tower).
In figure 1 light load is put far from the support. It gives as result a static equilibrium condition for the crane. It stays in upright position without any difficulties to balance. Figure 2 displays the exact opposite result. The lightweight material is now located very close to the tower. The body is now unstable and it overturns. The crane in this figure has collapsed. In figure 3 a heavy material is used as a load. It is pointed very close to the tower in order to achieve static equilibrium and disincline crane's collapse. Finally in figure 4 the position of the heavy load is as far as possible from the tower. It hasn't been achieved static equilibrium condition between the reaction forces and the applied load forces and the body collapses.

The reaction from the support in figures 1 and 3 is equal to the sum of the load which is applied. Also the moments at the right side of the tower are equal to those at the left side of the tower. In figure 1 it is clear that the distance between the load and the vertical tower is bigger (because of the light weight load) than the one in figure 3 in which is representing the heavy weight load.

In figures 2 and 4, unstable equilibrium condition is observed which leads to the overturn and collapse of the crane. The moment created by the load multiplied to the distance on the left side

is not equal to the moment which is created by the counterweight multiplied by its distance at the right side. This indicates an unstable body which finally collapses.

## Conclusion

The moment which is produced does not only depend on the distance from the supported point but also from the load weight. For stable bodies the sum of forces and moments must be zero. Crane's stability is one of the many examples in real life that is supported on statics equilibrium.

## References

[1]The Washington Post, (2008), The stability of tower cranes, The Washington Post, [online] [24/10/10] http://www.washingtonpost.com/wpdyn/content/graphic/2008/06/16/GR2008061600077.html

[2] Ji T and Bell A J. (2006). Seeing and Touching Structural Concepts. University of Manchester. [Online] [24/10/10] www.structuralconcepts.org

[3] CONSOLIDATED – DECKRANE, How tower cranes work, CONSOLIDATED – DECKRANE [Online] [24/10/10] http://www.deckrane.com/info/towercrn.pdf

[4] Wikipedia, (2010), Crane (machine), Wikipedia, [online] [24/10/10], http://en.wikipedia.org/wiki/Crane_%28machine%29#Tower_crane

# 1.23 Stiffness of Columns

Vidhya Gopinathan

The following demonstration illustrates the increase in the stiffness of columns by the addition of horizontal as well as diagonal bracing members.

**Model Construction**

The column models were constructed using wooden stirrers (Fig 1.1), which were cut and glued to the required sizes.

Figure 1.1 Components used in Building of column models

Three crude column models were constructed as shown in Fig 1.2. Each was roughly the same length. Model I was build using four vertical members which were restrained together by horizontal members at the top and bottom. Model II was an advancement of Model I, containing horizontal restraining members even at half span. Model III, a further improvement, was stiffened using diagonal bracing members too.

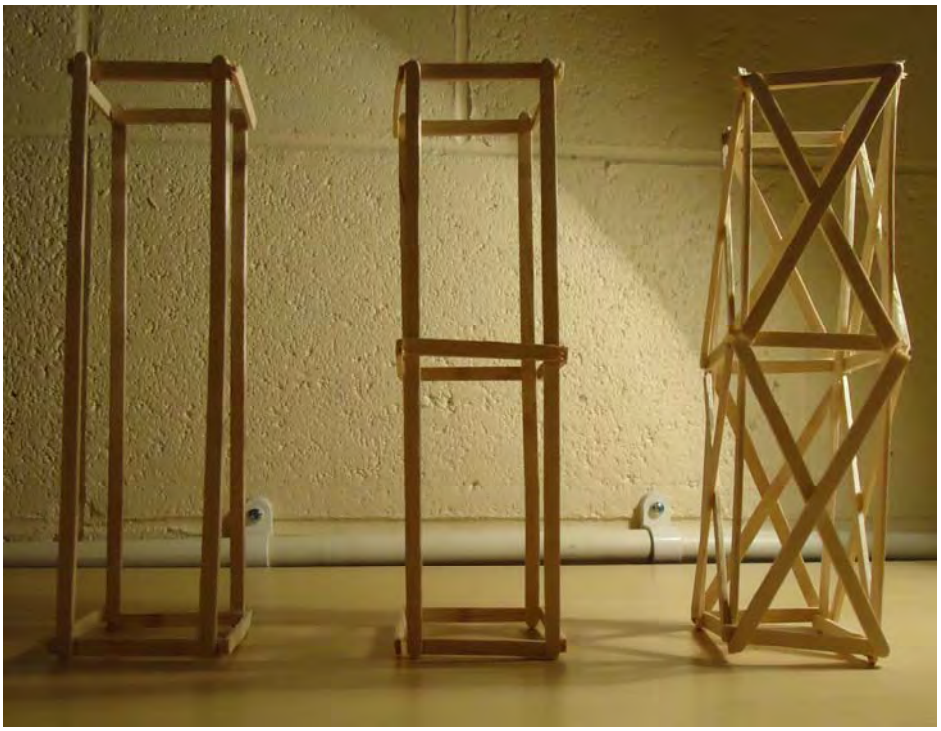


Figure 1.2 Column Models I, II and III from left to right

The three column models were loaded in turn with three different loadings. The loadings comprised of a wooden coaster and two note books, shown in Fig 1.3.

Figure 1.3 Coaster and Notebooks used as Loading

In order to provide a makeshift support to the base, each column model was fixed to the table using dough prepared from whole meal flour. The columns were then loaded in turn, first with the coaster and then the notebooks.

**Experiment and Results**

Model I was found to be highly unstable under the loading of the coaster (Fig 1.4) and it collapsed when the additional load of a notebook was applied on it.

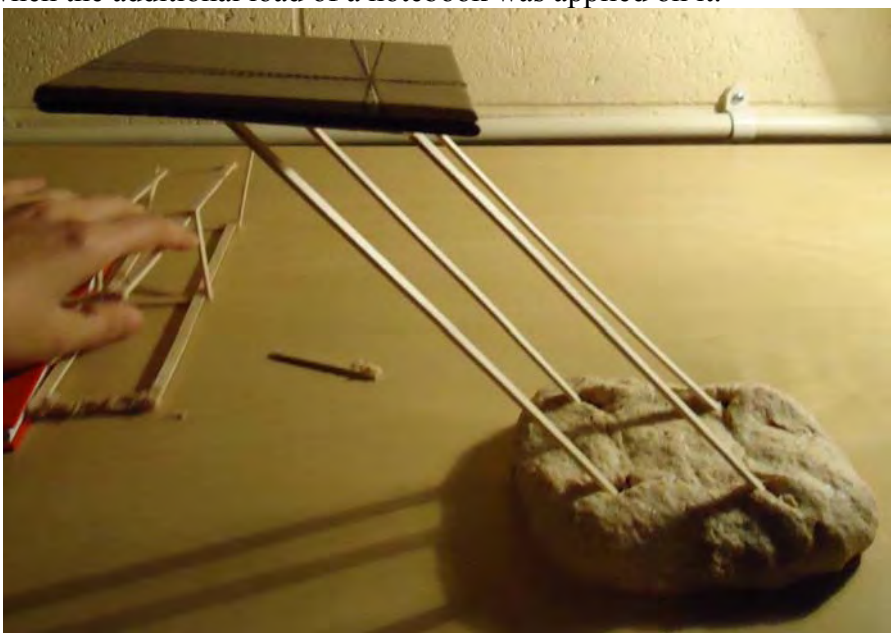


Figure 1.4 Model I loaded with the coaster

Model II was stable under the load of the coaster (Fig 1.5); however it soon became unstable when the notebook was placed on top of the coaster, as shown in Fig 1.6. Thereafter, model II collapsed under the load of the second notebook

Fig 1.5 Model II under loading of coaster

Fig 1.6 Model II under loading of coaster + notebook

Model III was able to successfully sustain the loadings of the coaster and the two notebooks, as shown in Fig 1.7

Fig 1.7 Model III under the loading of coaster + two notebooks

**Conclusion**

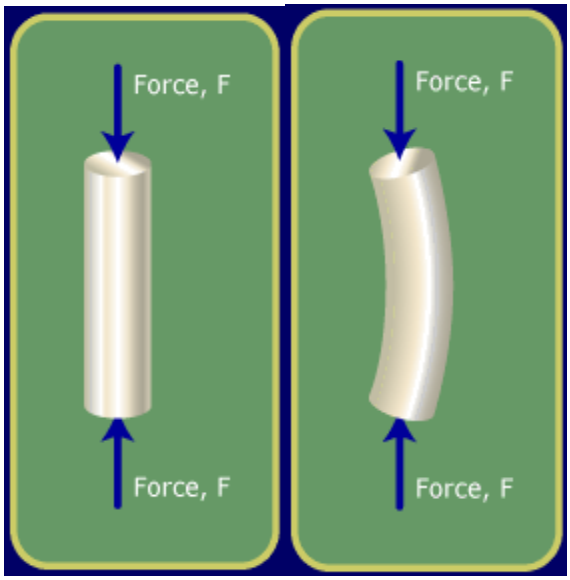
The stiffness of a column can be substantially increased by adding horizontal and diagonal bracing members enabling it to carry axial load more effectively. An accurate judgment of the buckling of the vertical members of the column models could not be made from the above demonstration as the fixity of the base was not adequate. However, it can be said that increasing the stiffness of the column by bracing will decrease the possibility of buckling of the vertical members of the column..

# 1.24 Effect of bracing on Slender Columns

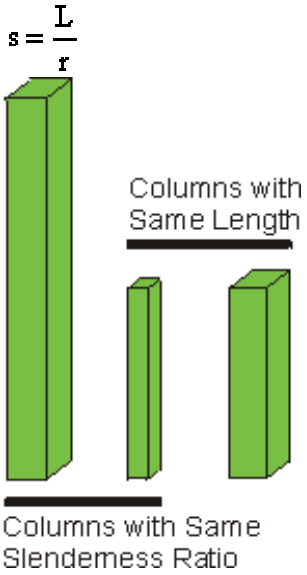
**Vidya Puliparambil Mohanan**

This model demonstrates the effect of bracing on buckling of slender columns.

When a perfect column is subjected to a compressive axial force as shown in figure 1,the only deformation that take place is a shortening of the column. For low values of F,if the column were to be deflected laterally by a force perpendicular to the column and the lateral force were thereafter removed, the column would return to its straight position, even with the force F remaining in place. This indicates a condition of stability. If the load F were increased, there is a value of Ffor which,when the lateral load is removed, the column is said to have failed from structural standpoint. Buckling can also be described in simple terms as bending or bowing of a column due to compressive load. This is illustrated in figure when a perfect column is subjected to compressive axial force as shown in figure when a perfect column is subjected to a compressive load. This illustrated in figure when a perfect column is subjected to a compressive axial force as shown in figure 1, the only deformation that takes place is a shortening of the column. For low values of F, if the column were to be deflected laterally by a force perpendicular to the column, and the lateral force were thereafter removed, the column would return to its straight position, even with the force F remaining in place. This indicates a condition of stablity.If the load F were increased, there is a value of F were increased, there is a value of F for which, when the lateral load is removed, the column would remain in the deformed shape. This condition is referred to as buckling and the column is said to have failed from a structural standpoint. Buckling can also be described in simple terms as bending or bowing of the column due to compressive load. (figure2)



The ratio of the effective length of a column to the least radius of gyration of its cross section is called the *slenderness ratio*



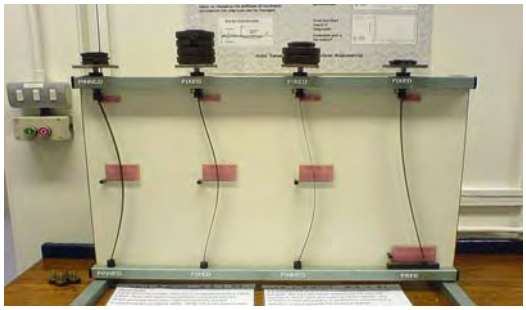



Fig 4

If your column is slender (height/width more than 15), you will need to design for the additional moments due to slenderness. you will need to be careful about slenderness and buckling (unless the load is very low or you can brace the column at half-height). If the load is very high then to prevent side sway and buckling bracing is provided. If bracing is provided it increases the load carrying capacity, the load will be carried by the bracings which will reduce the deflection of the column will be reduced.Figure 4 shows the buckling of column in different end conditions.

**Experiment:**
The column is subjected to axial vertical load and the buckling(deflection ) of the column is noted which is shown in figure 5.
Then the bracing is provided at the half height of the column and the same vertical load is applied through the axis and the deflection is noted.(which is shown in figure 6)

Figure 5

Figure 6

**Conclusion:**

From this demonstration it is clear that the bracing of the column will reduce the buckling of slender column,more the length of the bracing which reduce the deflection and buckling.

**Reference:**

Text book by, R.S.Ramamarutham,,"Design of concrete structures"

http://www.structuralconcepts.org

http://en.wikipedia.org/wiki/Buckling

1] Google images, search engine for various slender column cartoons. (Accessed at 24/10/2010)

# 1.25 Stiffness of braced and unbraced frame,

**wlat Karem**

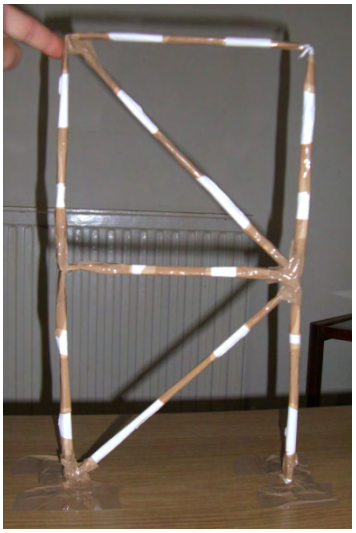
**The following frames made of paper each member is in cylinder shapes, they glued with brown coloured tape. It can be observed from the figure (1) that the unbraced frame (A) moves laterally as the Load applied to it as it shown in frame (B), where the braced frame (C) all most does not move at all with the same load applied to it as it shown in frame (D). The differences are frame (C) have an additional members which are supporting the frame by transferring the load applied to it to the foundation, the members are connected directly to each other that will make the frame even stiffer because without the knowledge how to connect members to increase stiffness it would be waste of materials as well as cost effects.**

**Figure (1) braced and unbraced frames**

**Frame (A)** unbraced frame without lateral force applied to

**Frame (B)** Unbraced frame with lateral force

**Frame (C)** Braced frame without lateral force to



**Frame (D)** braced frame with lateral forced applied

# 1.26 Stress Distribution of Human Actions

**Xi Li**

Concept: Stress Distribution
Practical example: Different Human Actions

The definition and concept of Stress Distribution: For a given external or internal force, the smaller the area of the member resisting the force, the higher the stress.

Figure1

Figure2

The figures above show a monk who used his index finger to support his body. In this model, the area which undertakes the force is very small. According to the stress distribution, the stress at the top of the finger is very high. So the monk who performed this action must practice a lot in order to make his index finger strong enough to withstand the high stress. Otherwise it'll be easily got hurt from doing this kind of action.

Figure3

Figure4

The action showed on Figure3 is also a very hard one. The Ballet dancer keep standing there by using her toes to undertake the forces produced by her body. The area which contacts with the surface is very small. So the stress on the her toes is very high.

Compared to the former two examples, the last one is easier to do. It's a headstand on Figure4.The contacting area is much bigger, because the people used both of his hands to support his body. As a result, the bigger the area of the member resisting the force, the smaller the stress.

Conclusion: we can use an equation to conclude this kind of stress distribution

$$\sigma = \frac{F}{A}$$

F---force; A---area; $\sigma$ ---stress

If A gets bigger, $\sigma$ gets smaller;
If A gets smaller, $\sigma$ gets bigger.

Reference: http://www.structuralconcepts.org/

# 1.27 Example one operating amphitheatre upper structure

**Xianjun Mao 7585431**

This example is found by Eduardo Torroja, 1899-1961, who was a Spanish professor in engineering and also a structural designer.

It was said that there was a operating amphitheatre to be built in the city center in Madrid. The diameter of the plane is 70ft (around 21.34m), and there was a vertical dormer window in the roof with a plane diameter of 32ft (around 10m). Below is the diagram which I obtained from internet book.

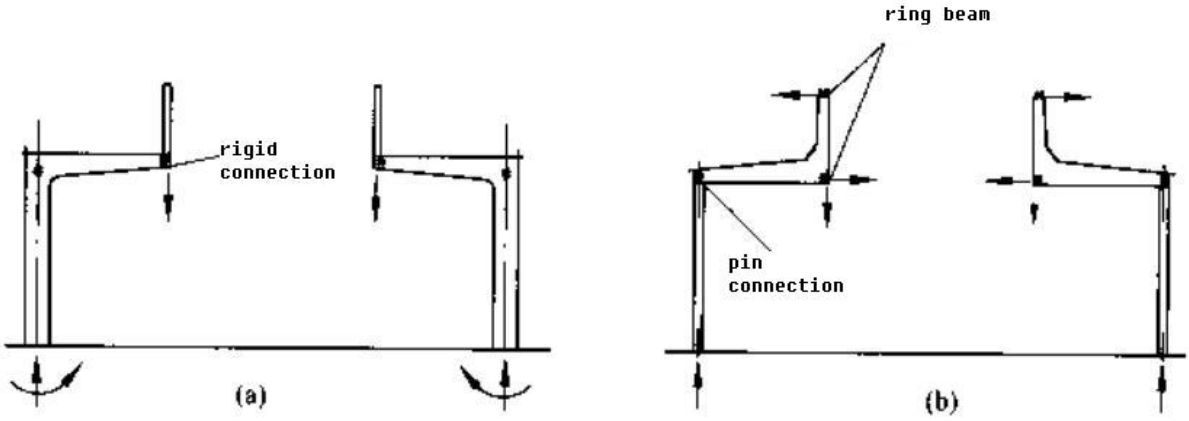



Diagram I

What are shown above are two choices of the construction plan at that time. Both two graphs are side view of the structure.

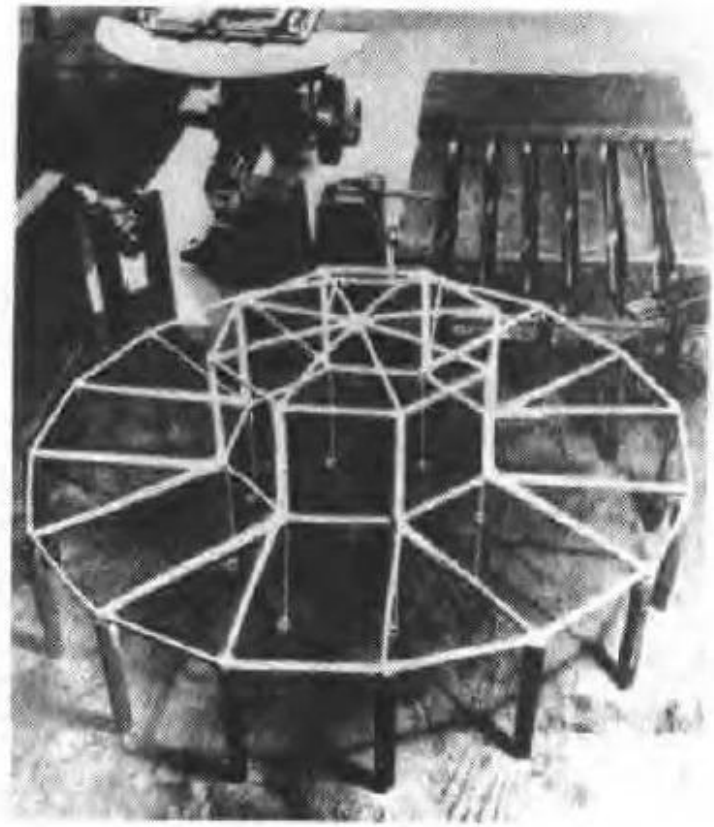
If planned as we did in the time before, we might choose plan (a), in which up-side-down L shape columns may be set up to support the vertical loading and the bending moment cause by foundation support and the loading. The only result of this, we might be able to foresee before we finish our design, is the surprising big sizes of the cross-section of columns which we certainly would like to avoid.

However, the engineer, I mentioned above, Eduardo Torroja, he chose to make plan (b) work. Now, let me explain what he did. Firstly, he chose a pin joint between the supporting column and the structure of dormer window instead of choosing a whole up-side-down L shape column. Secondly, a truss connecting through the center of the plane circle (a 3-D experimental photo will be shown later) was put into use to make the structure of the dormer window withstand horizontal forces as well. This can be seen from the picture (b) above. The truss connects both upper side and the lower side, providing two anti-direction forces to the dormer structure. And it is these anti-direction forces that make a couple which will counterbalance the huge bending moment caused by loading and foundation support.

The beneficial outcome of choosing plan (b) is transparent. When constructing a building, we want as much inner space as possible. In the light of this rule, plan (b) will bring us to more

internal space and smaller cross-section area in columns. Moreover, it is economy that most businessmen consider when it comes to construction. The plan (b) will, to a large extent, reduce the budget, so as a result, it would be, or it might be welcome by most construction companies.

Besides the theoretical analysis, experimental data is also valuable. One diagram illustrating how to do the experiment is shown below.



Model Testing of A Smaller Scale

Diagram II

Through this structural concept studying, I realize that not only theoretical analysis is required, but also creative imaginations as well as an overall grasping of the whole structure are of vital importance to make our structural design a more stable, feasible and economical one which would best show what we have learnt and what we have thought.

Reference
Website :
http://books.google.com.hk/books?id=UimEUU7Y6VwC&pg=PA58&lpg=PA58&dq=%E5%9C%86%E5%BD%A2%E6%89%8B%E6%9C%AF%E6%95%99%E5%AE%A4&source=bl&ots=17I7UxW3Yf&sig=0vyFhuUklkMgrQfaZABx039mLEk&hl=zh-CN&ei=PnfATKHSB4mK4ga804GgDA&sa=X&oi=book_result&ct=result&resnum=6&ved=0CCgQ6AEwBQ#v=onepage&q=%E5%9C%86%E5%BD%A2%E6%89%8B%E6%9C%AF%E6%95%99%E5%AE%A4&f=false
Book:
Structural Analysis, 3rd edition, R.C.Coates, M.G.Coutie, F.K.Kong

# 1.28 A Test of Cantilever Beam

Name: Yahui Guo  Student ID: 73032360

A. Observe the displacement at the free end of the cantilever with a span of say 350mm. It can be seen from Figure (a) that there is a small deflection at the free end.

B. Double the span to 700mm as shown in Figure (b) and a much larger end displacement is observed. The end deflection for a span of 700mm should be eight times that for a span of 350mm when the effect of the self-weight of the ruler is negligible in comparison to the weight of the metal block.

C. Turn the ruler through 90 degrees about its longitudinal axis as shown in Figure (c) and repeat the tests when much reduced end displacement will be soon. Deflection is proportional to the inverse of the second moment of area which for a rectangular section is given by $I=bh^3/12$. For the current test, the second moment of area of the section about the horizontal axis is 36 times that of the section used in the last test, resulting in maximum deflections of about one thirty-sixth of those in the second test( Figure b).

a

b

c

Figure (a, b, c) Deflections of a cantilever beam subjected to a concentrated load

# 1.29 Centre of Mass and Stable

**Yi Yang**

The following model shows the relationship between the location of centre of mass and the stability of structures. The structure of the model is a sanitary cup, which is shown in the following pictures, and the pink line on the cup shows the position of centre of mass.[1]

It verified that the lower the centre of mass of a body, the more stable the body is.

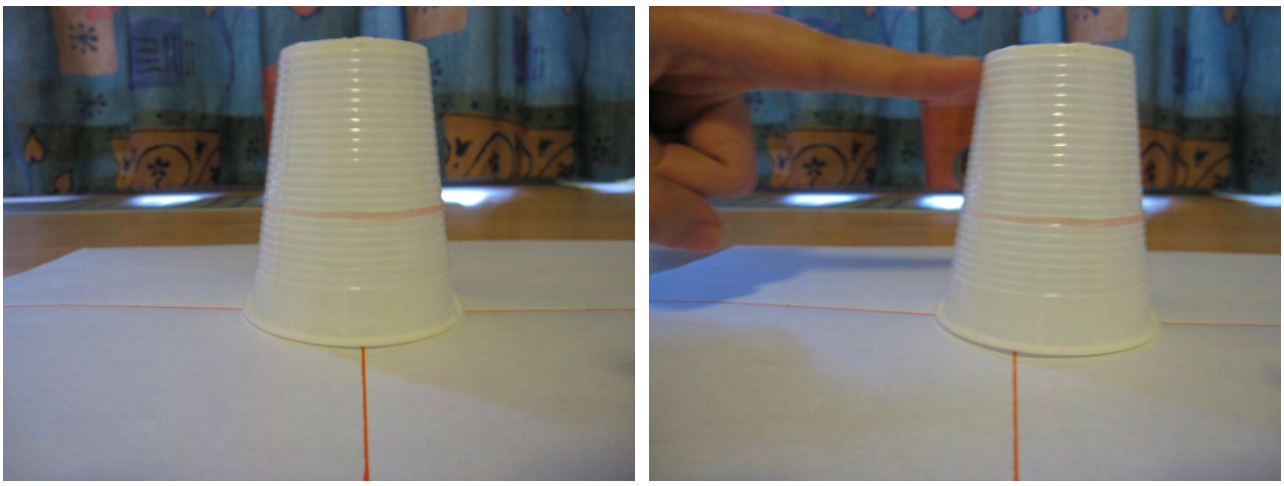


Figure 1.1-1.2

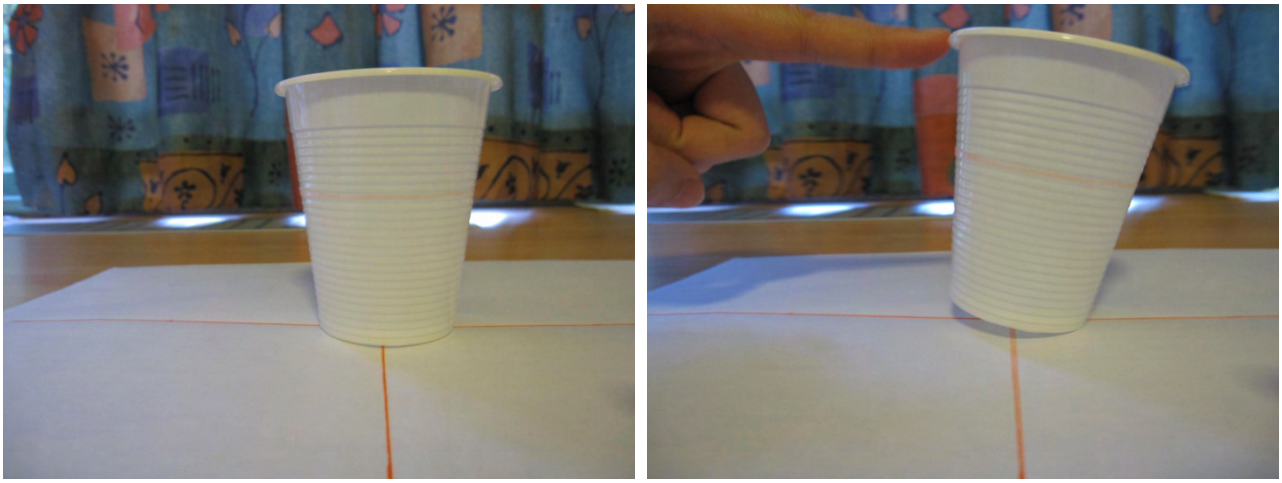


Figure 2.1-2.2

## Explanation

Comparing figure 1.1 and figure 2.1, the main difference of the two sanitary cups is the position of the top and the bottom.

Place the cup as the figure 1 shows, when a horizontal force is imposed, there is no sway.

[1] The position of the centre of mass is an approximate value without accurate calculation.

When reverse the top and the bottom of the cup as the figure 2 shows, a horizontal force can easily cause a sway displacement.

The position of the top and the bottom of the cup only can result in the difference of the centre of mass: the centre of mass in figure 1 is lower than that in figure 2. Comparing the sway displacements in the figure 1.2 and 2.2, a conclusion can be drawn that the lower the centre of mass, the more stable the body is.

**Application**

In a **QUIZ**

The following graph shows three frames with different shapes. When the same horizontal forces impose on these frames, which one will get the most serious sway displacement?

The cross sections of three frames are same.

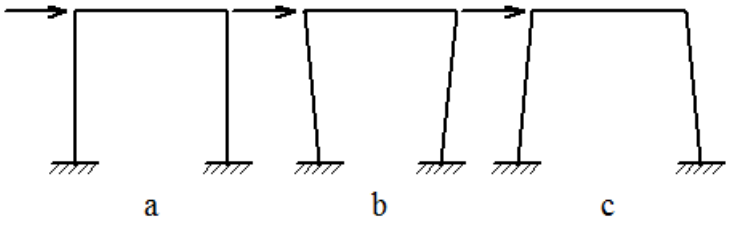



Figure 3

ANSWER: b

Comparing the centre of mass in these frames, b>a>c, so the sequence of sway displacement is: b>a>c. Choose b as the answer.

In an **ARCHITECTURE**

This theory is also applied in the architectures, especially the high-rise buildings and towers.

Figure 4 CCTV Tower

Figure 5 Tianning Temple pagodas, China

**Reference**

T. Ji, A. Bell. *Seeing and touching structural concepts*. Available at: http://www.mace.manchester.ac.uk/project/teaching/civil/structuralconcepts/ (Accessed: 24 October 2010)

# 1.30 Local Buckling of Thin Columns

**Yuliyan Yuriev Paunov**

This model demonstrates the effect of high thin columns buckling are formed by many beam supports by the only use of vertical load. Axial loading is applied to the columns and the buckling effect is observed.
In this experiment using some piece of cardboard, a scissor and a ruler, the shape of system is made as follows;

In this experiment the system is used in two ways. At the first time in the upper and lower part of the model i used trusses because of make it stiff. In figure 1.b. we can see that if we used beam supports only some part of columns and axial load applied on it. The columns buckle under the loading.

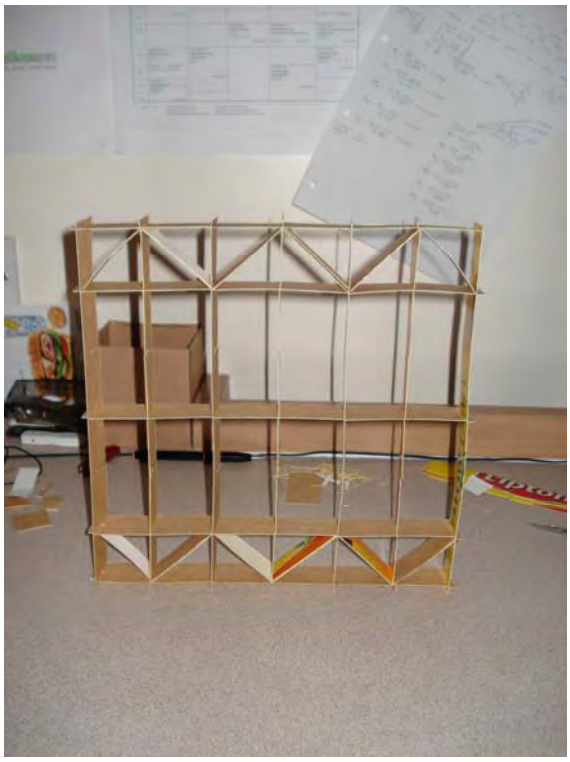


Fig. 1.a.

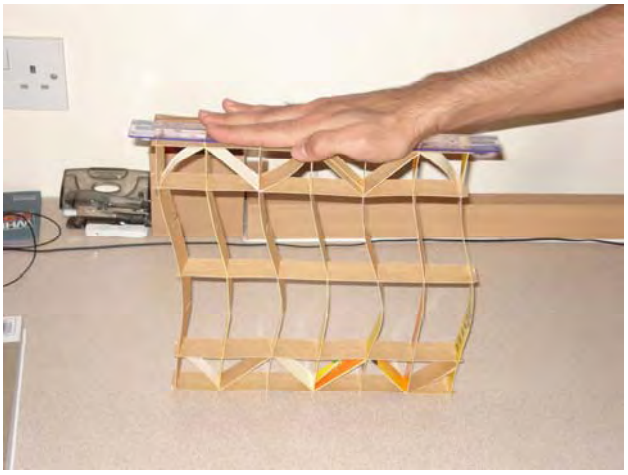


Fig. 1.b.

At the second time in the right hand side and left hand side vertical part of the model, again i used trusses because of make to side more stiffer than middle. So in figure 2.b. the numbers of beams are increased and the middle beam is reduced from the center. The same amount of loading is applied and here we can observe that the columns do not buckle much when compared to first figure except a middle column .

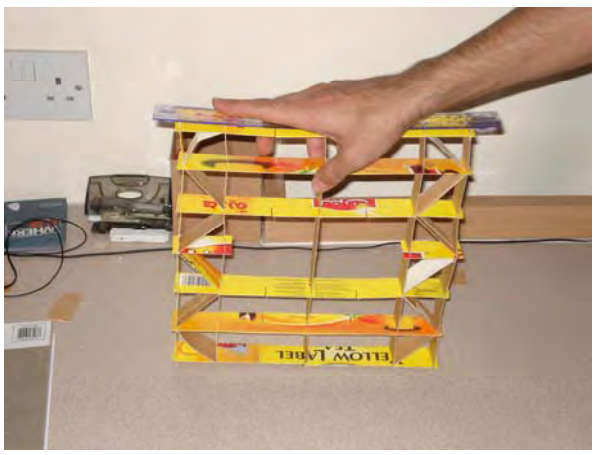


Fig. 2.a.

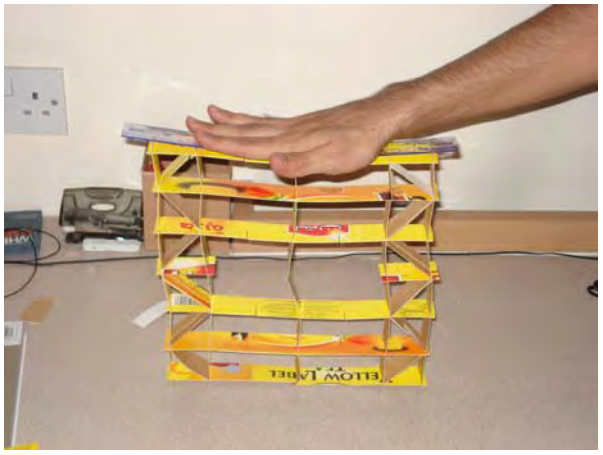


Fig. 2.b

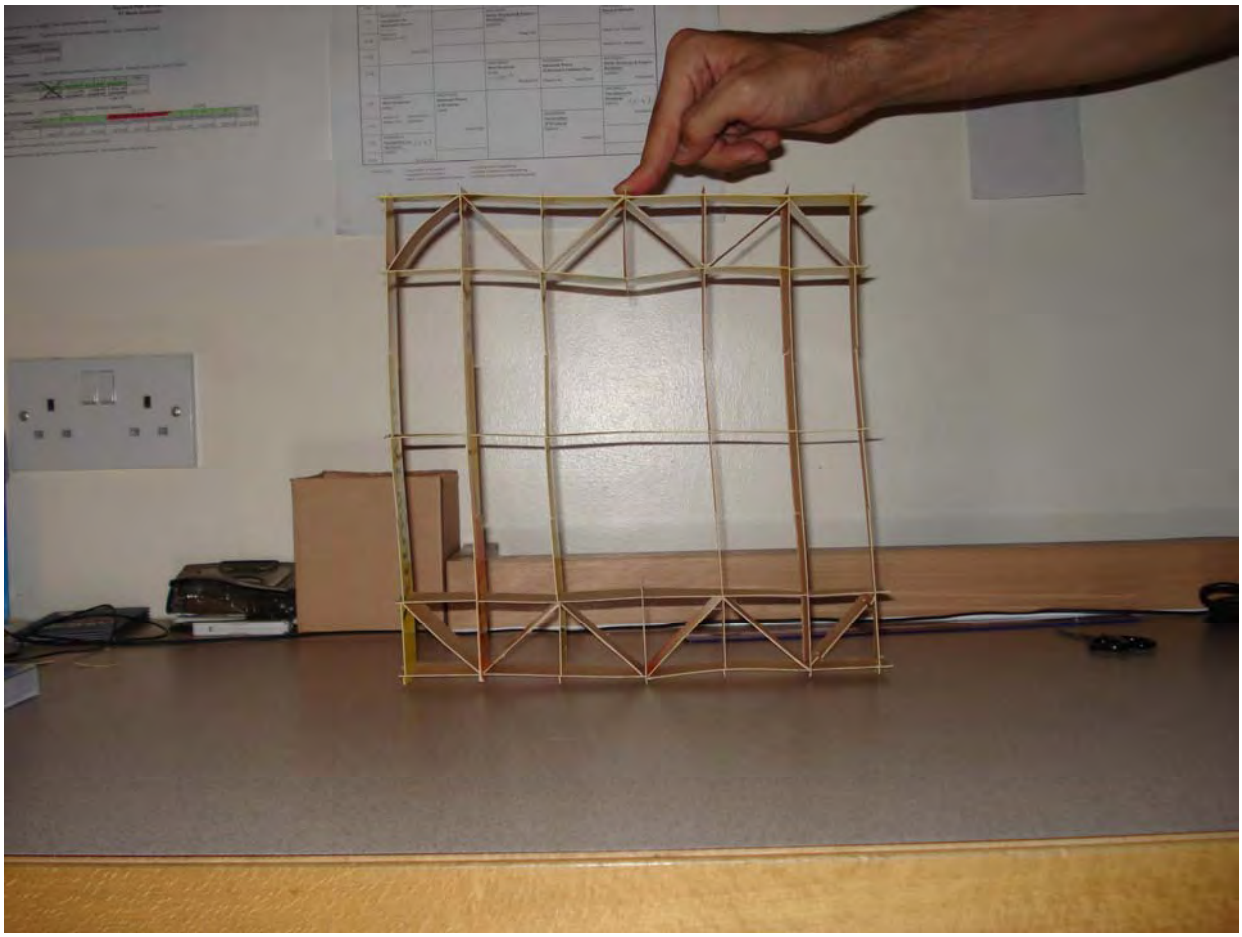
Euller differential equation shows that;

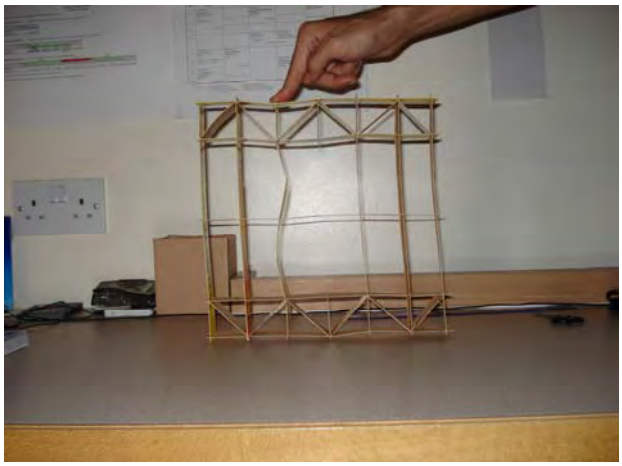
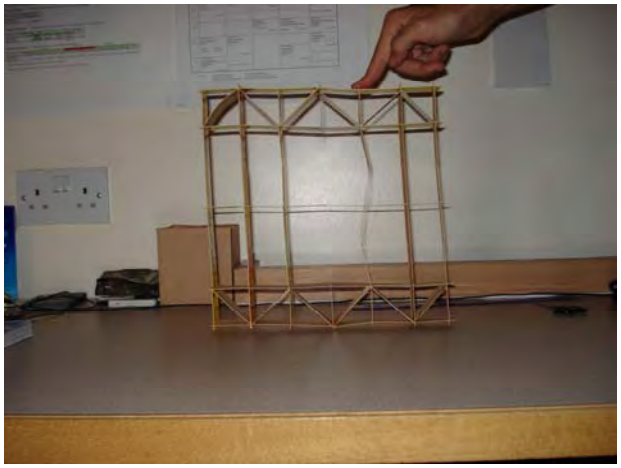
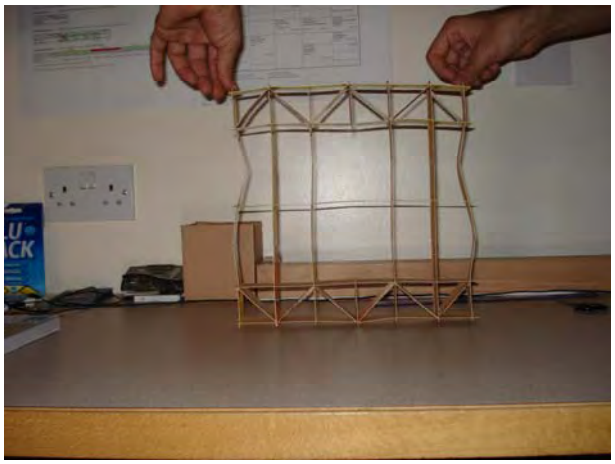
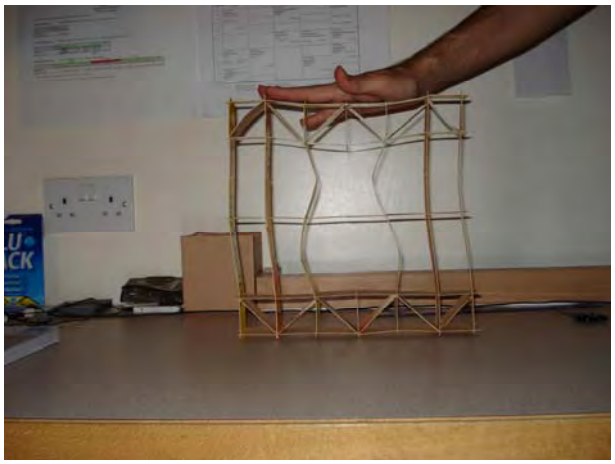
$$P_{cr,e} = \frac{\pi^2 EI}{L^2} \qquad [1]$$

So in this equation if the length of the column L is very high, the critica axial load can be very low because L square. Also we can see the critial load is depands on the moment of inertia and elasticity modulus.

After observing the columns we can conclude that the cross sectional property and the lenght of any section of any member changes the material property.

Other experimental experiences with a same model;



**Reference:**

[1] Devrim Ozhendekci, Lecture Notes, Available on http://www.yildiz.edu.tr/~devrimo/Devrim_Ozhendekci_Celik1_Ders-Notu-6.pdf

# Examples

# 2.1 Concepts of Stress Distribution, Pre-stressing and Buckling modelled on an expending file folder

**Abdoulahate SECK**

"For a given external or internal force, the smaller the area of the member resisting the force, the higher the stress" (Ji and Bell 2000). In other words more uniformly stressed members carry more loads before failure. The following model constitute a plastic expending folder representing a beam loaded by a mouse as illustrated in fig1.

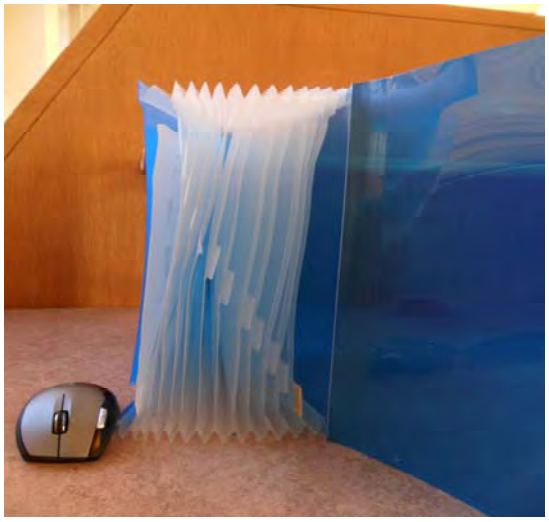


Figure 12: Expending Folder and Mouse used

In the first experiment fig 1.a, the mouse is oriented as a point load and the area of contact is kept to a minimum ($0.4\times10^{-4}\ m^2$). As we see the deflection is so large that the beam (expending folder) collapse.

Figure13.a: Point Load on Beam high deflection Figure 14.b: Distibuted Load on Beam low deflection

In fig1.b the loading mouse is positioned on plan and a greater area of contact is achieved ($62\times10^{-4}$ $m^2$). Note that care was taken to have the same expending distance than in figure 1.a. As a result the deflection of the beam is far lower. The beam carries correctly the same load 10N .
This conclude that “the more uniform the distribution of internal forces, the stiffer the structure” (Ji and Bell 200).

In the second experiment figure 2.a the file folder is expended and left on its own. When loaded it shows significant deflection. That’s the behavior of a normal beam.

Figure 2.a: Normal sagging on expended folder

Figure 2.b: No sagging on compressed expended folder

In figure 2.b the strips or dividers of the folders are hand compressed as shown above. Care was taken so that strips don’t touch one another to form any shear connections. The result is a pres-stressed top beam that allow little to no deflection when loaded by the mouse. It can even carry further load.
This confirms that pres-stressing provide higher stiffness to beams.

In the last experiment strips or dividers are looked at as column members. The figure 3 show that when loaded on top the strip deflects laterally and fails by combined bending and compression as explained in a case of buckling (Ji and Bell 2000). It mirrors the bluckling of a slender column with two pinned ends. When a shear connection (Hand compression) is applied and strips acting together a smaller buckling is observed.

Figure 3:Lateral Buckling on slender strip and non slender strip

References:

Ji and Bell (2000) Seeing and Touching Structural Concepts. from

http://www.structuralconcepts.org accessed on 23/10/10

# 2.2 How to Sleep on a Rope

**Chenxiang Xu**

**Caution: Imitation Causes Hundreds of Pain!!!**

## Background

Couple weeks ago, a labourer turned up at Hangzhou Railway Station, China with a rope in his hand. In the crowd watched, he tied the rope on fences and took a nap on the rope!

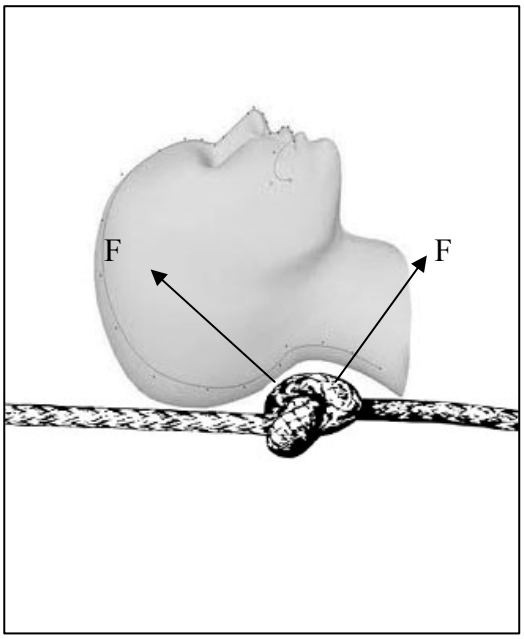
This amazing skill attracted people's attention; even journalists came to interview him. He explained the his experience to people around him, which included three key points： put the neck on the top of knot, twine legs with the rope and more important, make body peaceful.

## Model Analysis

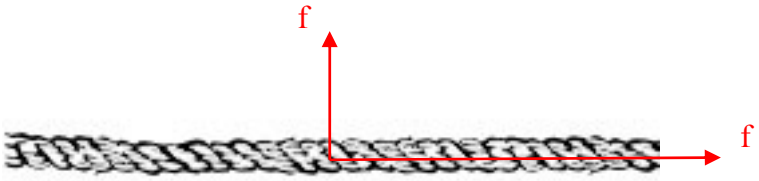
What made it happen? Reasons will be explained in a science way below,

- Centre of Mass
  To make the body stable on the rope, centre of mass of the body must be located on top of the rope. Human body is symmetrical. Therefore, centre of mass of the body must be in the symmetric line of the body. According to the photo, the symmetric line of the body is on the top of the rope. The reaction force provided by rope can support the body effectively.

- Knot under neck
  Picture on the right shows the structure of neck when people sleep. The knot will be fit the curve between the neck and head. As a kind of support, it will provide forces against the movement of head and neck.




- Twine legs with rope
  Twine legs with rope increases the contact surface between human body and the rope. As legs clamp rope, rope provides static friction against movement both in vertical and horizontal direction.




- Make body peaceful
  This can be understood as don't move a lot. Although a rope can provide enough support to a human body's weight, the contact surface is quite small. A little movement of part of the body will cause moment and imbalance. How much people can move proportional to the diameter of the rope.

## Conclusion

Sleep on a rope is not impossible anymore. All people need to pay attention is trying to increase the force against movement and following the principle of equilibrium. However, this is still not easy to learn. There are hundreds of failures before success. Furthermore, don't really fall asleep when you are on the rope!!

## Reference

Pictures supported: http://news.sohu.com/20101021/n276136191.shtml

# 2.3 Centre of Mass.

**Farhan Hariz Hisham (7695241)**

Air traffic control towers are normally high rise buildings which are higher than the surrounding buildings. This enables air traffic controllers to monitor the traffic for both aircrafts on the ground as well as in the air.

Air traffic control towers usually consist of a long cylindrical structure with an operations room located on the top of the structure which is normally larger than the cylindrical structure. This increases the possibility of the structure to topple over due to the high centre of mass and its exposure to wind loading. Examples of air traffic control tower toppling are shown below:

To encounter this problem, the centre of mass of such structures can be lowered to ensure more stability in the structure. An example of this can be seen from the London Heathrow Airport air traffic control tower located close to Terminal 3. The structure consists of a triangular mast section with a cone shaped operations room located at the top.

To ensure the stability of the control tower, an enlarge base which stores a collection of technical equipments is constructed at the base of the tower. This lowers the centre of mass of the structure hence increasing its stability. Also to further increase its stability, tension cables were also added to restrain any swaying movements of the structure.

**REFERENCES.**

1) Tianjian Ji, Adrian Bell, Seeing and Touching Structural Concepts.

2) Architecture.com from the Royal Institute of British Architects. http://www.architecture.com/Awards/RIBAAwards/Winners2007/London/Heathrow/HeathrowAirTrafficControlTower.aspx

# 2.4 ENERGY EXCHANGE – SUSTAINABLE DANCE FLOOR

**GAUTHAM SATHISH**

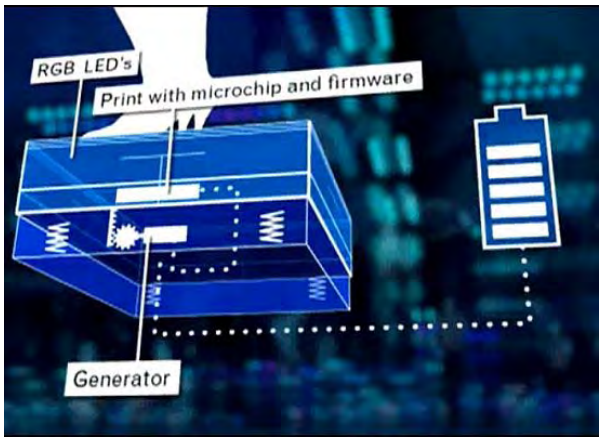
## INTRODUCTION

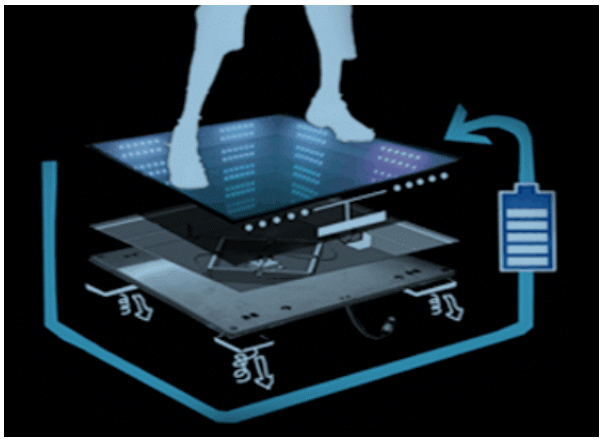
According to the law of conservation of energy, energy can be transformed from one form to another. A Sustainable Dance floor uses the same concept of energy exchange. It converts the human mechanical energy induced on the dance floor by the dancing crowd, into electrical energy which can be utilized to meet the electrical demand of the Night club. The energy conversion is based on the principle of piezoelectricity. The world's first sustainable dance club was the 'Watt club' in Rotterdam, Holland.

## MECHANISM

The sustainable dance club is a creative concept by a Rotterdam based company ENVIU. Sustainable dance floor comprises of a number of 650x650x195mm-sized modules which acts as a small power plant. When being stepped on, the floor will compress by 10mm. The floors are suspended on transducers, which converts the energy and also acts as shock absorbers. The energy is absorbed using piezoelectric crystals which when compressed, charges the nearby batteries. Multiple modules are connected to each other to form a dance floor. All energy floor modules are connected to a controller module where the energy is stored. LED lights flicker on

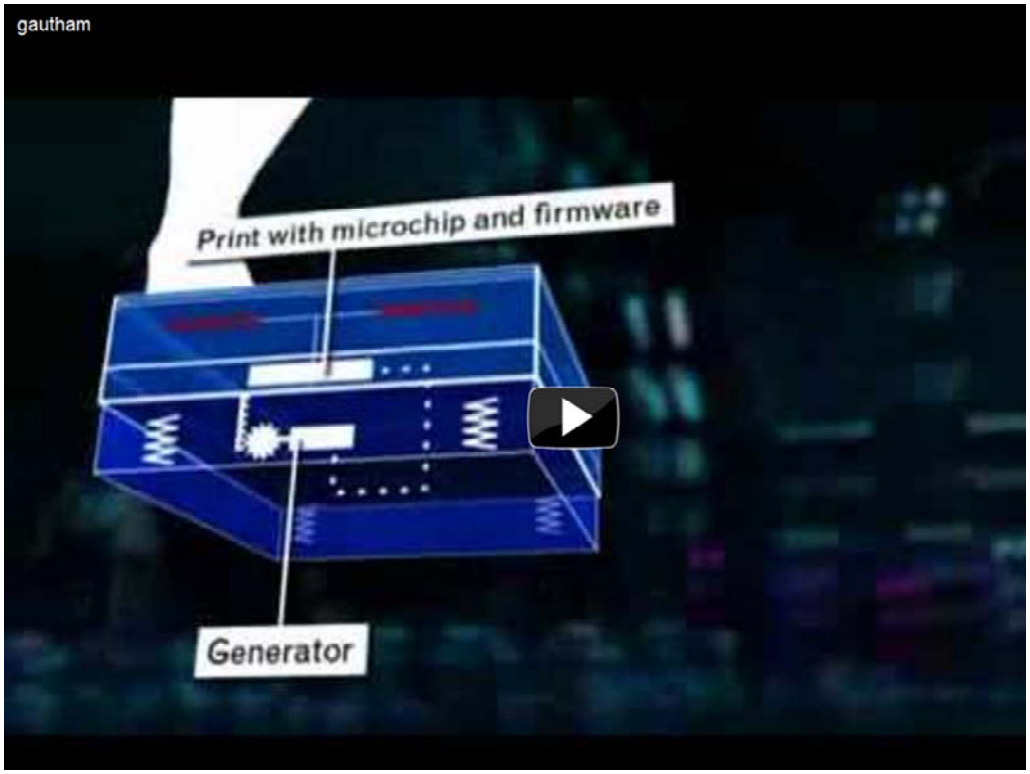
and off in each tile, and a monitor screen shows the dancers the relationship between their movement and the energy they are generating.

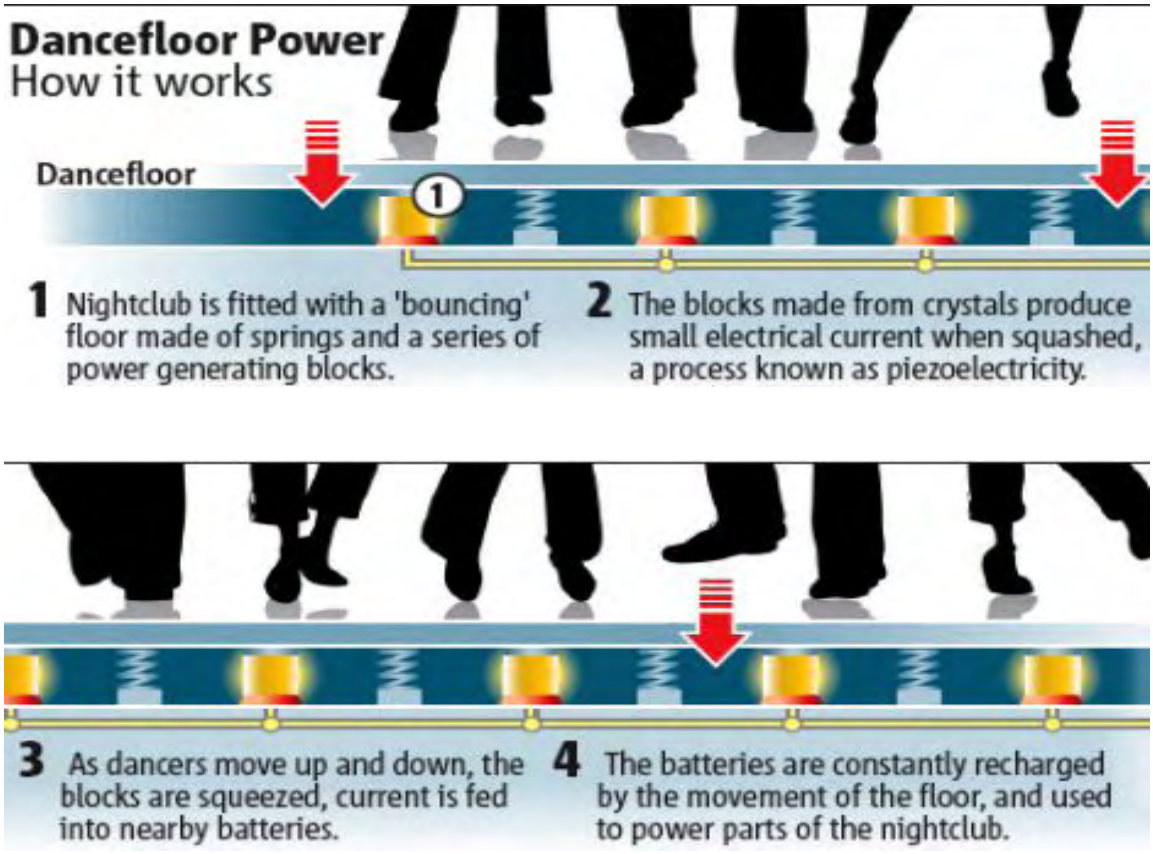


**VIDEO 1 - MECHANISM**

**(Double click on 'Play' button below to view video)**




Dancefloor Power
How it works
Dancefloor
1
1 Nightclub is fitted with a 'bouncing' floor made of springs and a series of power generating blocks.
2 The blocks made from crystals produce small electrical current when squashed, a process known as piezoelectricity.
3 As dancers move up and down, the blocks are squeezed, current is fed into nearby batteries.
4 The batteries are constantly recharged by the movement of the floor, and used to power parts of the nightclub.

The innovative idea of sustainable dance floor developed by SDC and ENVIU was much appreciated as an environment friendly concept. A number of green night clubs have adopted this technology since the dance floor is capable of generating 30-60% of the building's electricity.

**APPLICATION**

According to the United Nations, the world must reduce greenhouse gases between 25 percent and 40 percent by 2020 to prevent dangerous warming. In order to prevent global energy crisis, energy consumption must be efficient and greener and must rely on renewable energy resources. Green construction techniques should be adopted combining technology and manpower, in such a way that most form of energy is conserved. For example, during training, Olympic athletes use fitness machines, that do nothing but provide resistance to muscle power. If the fitness and gymnastic machines were redesigned to produce and store electricity from the human power, it would become an abundant renewable, non-polluting source of energy.

**REFERENCES :**

1.http://www.dailymail.co.uk/sciencetech/article-1027362/Britains-eco-nightclub-powered-pounding-feet-opens-doors.html

2. http://www.youtube.com/watch?v=ClIBN92wRF4

3. http://www.greendiary.com/entry/bouncing-dance-floor-at-club-energy-generates-electricity-from-body-movement/

4. http://www.youtube.com/watch?v=xoewlHwI3U4

# 2.5 "PLAYING" WITH STRUCTURES

**Name: Ioannis Pappous**

## PART 1: GUITAR

As an engineer, one thing that you learn is to look everything around you from skyscrapers and bridges to ships and radio antennas. Engineers have their own way of looking things through hypercritical eyes that always make us wondering and asking ourselves "how and why". We can understand many things about structural concepts simply by looking around. A guitar is the example I will examine.

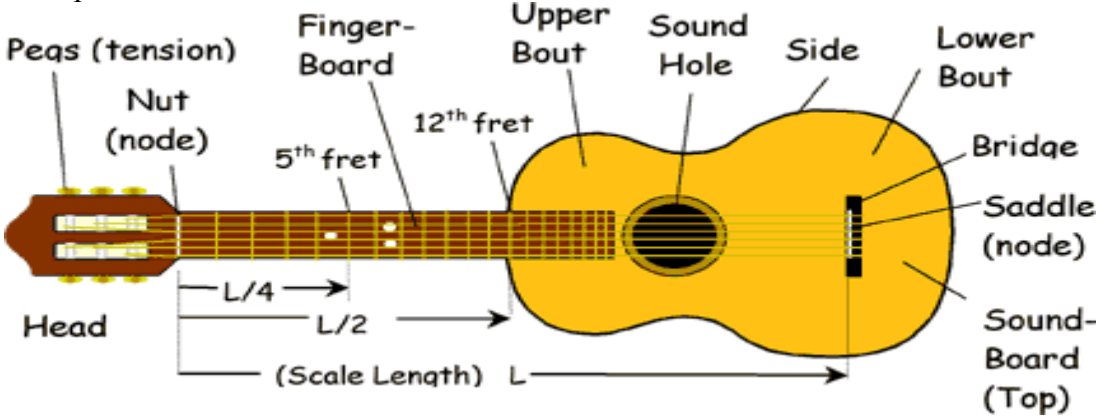



*Figure 1: Parts of a guitar*

The guitar involves many structural principles, among them: stress and strains, frequency of vibration, wavelength and period, as well as elastic limit and damping. So, let's play around.

### Stress and Strain

A common guitar consists of six strings and each one is under tension. The top of the guitar (sound board) has to be strong enough to resist the tension produced by the strings as well as lightweight and thin so that the sound will be amplified.

When you use the peg to tune the guitar a moment is created with the peg, while the hand creates a torque as it moves causing rotation about the peg. As a result stress is applied on the string which is stretched. The magnitude of stretching in the strain is due to the tension that makes it get longer and thinner. What we care of is the stress that was applied, meaning the force per unit area of the string. However, we cannot measure the stress on the string so we measure the displacement-elongation that it's immediately associated to stress.

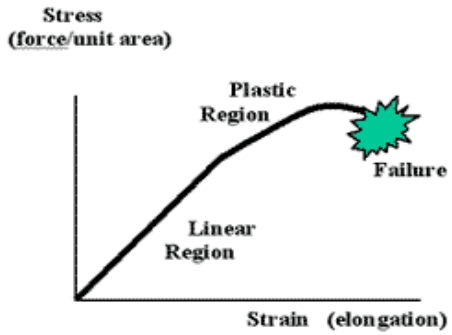


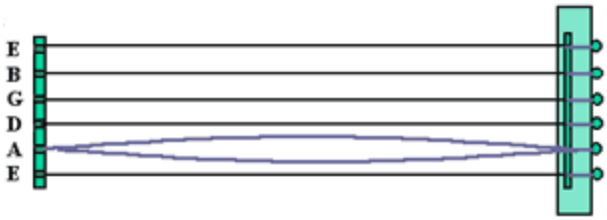

*Figure 2: Stress-strain relationship*

For most materials the percentage of strain is related to stress by a constant as long as the material is in the elastic region. So if the string is in the elastic region we can measure the actual stress applied. If the string doesn't return to its equilibrium position, must be retuned once in the plastic region the Young's modulus is not constant, so the frequency of vibration doesn't go up and down proportionally making the sound vigorous.

**Frequency of vibration (resonance)**

Practically everything resonates, from the molecules that make up our bodies, to bridges and buildings. The same with the guitar, tuning the strings we can observe that they return to its point of rest (equilibrium) after moving up and down under a specific frequency. This is called resonance and the resonant frequency is directly related to the length and the tension. So if these two remain the same, the frequency is always the same for the strings.

The strings act like springs. Tensile forces are applied in line with the longitudinal axis of the string. When tuning the peg, the tension on the string increases or decreases. Sometimes the strings might be stretched above their elastic limit. Strings are also related to temperature changes and ageing resulting to variations in tension.




Every string is supported on two nodes, the nut (head) and the bridge (saddle). When the strings are tuned, they are not allowed to move at the ends but only at the middle (finger board).

*Figure 3: Vibration of string*

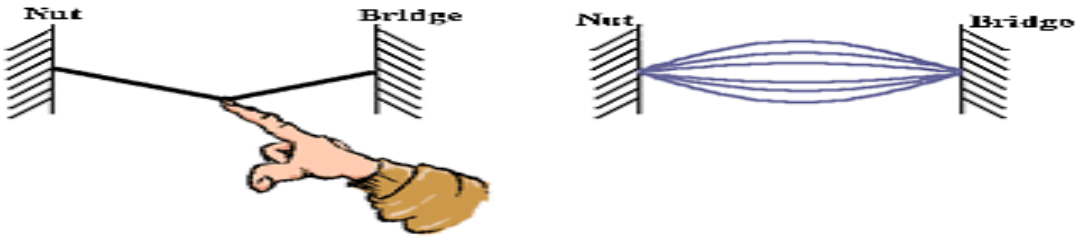
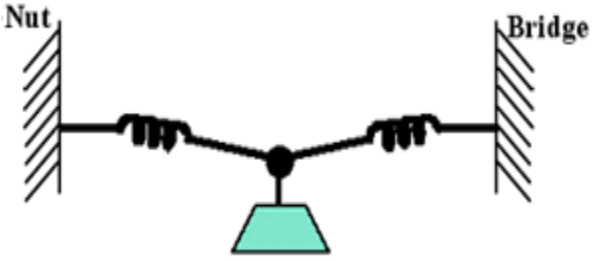



*Figure 4: Strings fixed at both ends like a beam*

It is obvious that the strings act like a beam fixed at both ends. When the force (tuning) is inserted, the strings after vibrating up and down return to its normal mode of vibration.




If we want to present the spring as a model we can relate the strings to springs once they behave almost the same and the tuning applied on the spring by the peg as a mass at the midpoint. If we increase the mass the frequency of vibration decreases.

*Figure 5: Engineering model of a guitar*

For a perfectly tuned guitar the frequency of vibration, according to manufacturers is 440 Hz. So the period in which the tune will vibrate, meaning the time taken to move from one side to the other and back again, can be calculated from:

- T=1/f
- T= 1/440 = 2.273 ms

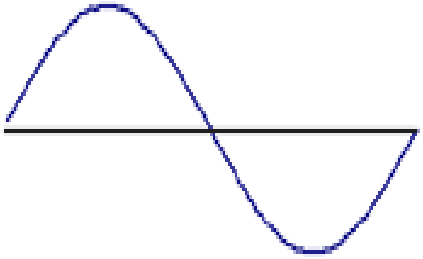


*Figure 6: Free vibration*

We observe that the frequency vibration is the same as the frequency of a frame structure and can be mathematically expressed as:

- v(t) = X* sin 2* π* 440* t

# 2.6 "PLAYING" WITH STRUCTURES

**Name: Ioannis Pappous**

**Part 2: Seesaw**

Every day, without even thinking about it we make use of devices or equipments that their use and operation is based on the same structural concepts as for buildings, bridges and all the existing structures.

A seesaw is a long board mainly found in playgrounds and is used by children as a game for entertainment. It is usually consisted of a long wooden board with two seats, one at each end of the board.

*Figure 1: A seesaw in a playground*

The long board is balanced and supported on a central point. This point acts as a pinned joint that is pivoted and as a result is allowed to rotate. This central point is placed exactly at the middle of the wooden board making the two sides symmetrical, once the length is the same. In this way the seesaw is operates using the principles of equilibrium.

Specifically, when a child seats on one end and another child at the opposite end of the seesaw, the board will move up and down according to the weight of the children. If both children are of equal weights and the distance from the central support to the point that their weight is applied is also the same, then the board will be stable and there will be no movement. This is because the moments that are created at the center due to the forces applied by the weight of the two children are equal so are canceled out by each other.

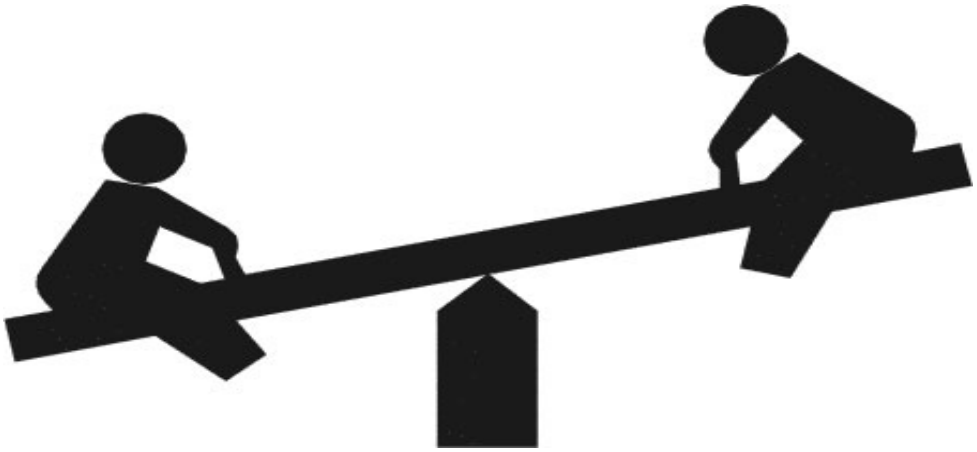


*Figure 2: A schematic illustration of a seesaw with two children playing on*

For instance, if the child at the left end of the seesaw was replaced by a child that weighs more, then the child at the right end would move upwards right away. This comes as a result of the moment that is induced by the heavier child, which is bigger than the moment that the lighter child induces, so the seesaw rotates anticlockwise causing an upward movement.

*Figure 3: The bigger the load, the bigger the moment (anticlockwise rotation).*

Supposing now the child that weighs more and seats on the left side, will move closer to the center point (the support). This will cause a reduction of the anticlockwise moment that is applied by the child on the left end and the result is a clockwise rotation of the seesaw causing downward movement of the child on the right end of the seesaw.

The final result from analyzing this model is that the moment depends on the amount of force applied and the distance between the support and the force.

Hence,

(Big Force*Distance) > (Small Force*Distance) and

(Force*Small Distance) < (Force*Long Distance)

The seesaw as a model can be related to the behavior of beams once the bending in beams is due to the moments applied and it is a form of rotation. Furthermore, equilibrium within moments is illustrated clearly on a seesaw, as well as how component forces affect the behavior of moment systems.

As a mechanical tool, a seesaw can operate as a lever that helps objects to be lifted by moving the support from the center closer to the object we want to lift.

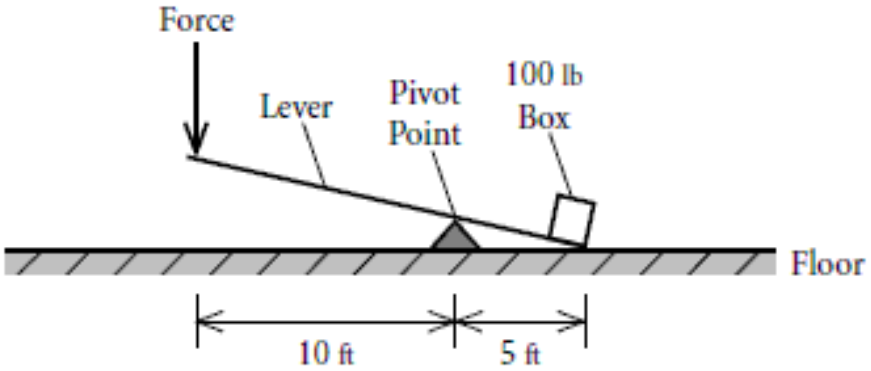



*Figure 4: Example of how a seesaw is used as a lever.*

So the 100 lb box could be lifted by applying a force F=50 lb.
F*10 ft =100 lb*5 ft.
Hence, F=50 lb half of the box that is to be lifted.

It is clear then that structural concepts of all the buildings whether are dwellings or superstructures, are all based on everyday's tools, machines and equipments that make our life easier or are used to entertain us and help us on thousands of things and activities that wouldn't have been done otherwise.

# 2.7 EXAMPLE OF PRACTICAL APPLICATION OF STRUCTURAL CONCEPTS

**MASEMBE SENDAWULA JULIUS**

## CABLE STAYED BRIDGES

A cable stayed bridge is a bridge that consists of one or more columns with cables supporting the bridge deck. Cables are used for the bridges because they are light with a high tensile strength and because they can create self balanced systems in the structures. The behaviour of this type of bridge can be considered using the concept of direct force paths. Due to the use of the cables, the loads acting on the bridge decks are not transmitted to their supports primarily through bending actions instead loads are transmitted mainly through tensile forces induced to the support tower with the horizontal components of the cable forces induced by the self weight of the bridge being self- balanced due the symmetry of the structure. Vertical components of the cable forces pass directly through the tower to the foundation.
There are two major classes of cable stayed bridges:

1. Harp design , the cables are made nearly parallel by attaching them to various points on the tower so that the height of attachment of each cable on the tower is similar to the distance from the tower to along the road way to its lower attachment.
2. Fan design, the cables all connect to or pass over the top of the tower.

The cable-stayed bridges are optimal for spans longer than typically seen in cantilever bridges and the towers form the primary load bearing structure. A cantilever approach is often used for support of the bridge deck near the towers, but areas further from them are supported by the cables running directly to the towers. This has an advantage of not requiring firm anchorages to resist a horizontal pull of the cables. All static horizontal forces are balanced so that the supporting tower does not tend to tilt or slide, needing only to resist such forces from the live loads.
The key advantages of the cable stayed form are as follows:

1. There is much stiffness so that deformations of the deck under live loads are reduced.
2. Can be constructed by cantilevering out from the tower – the cables act both as temporary and permanent supports to the bridge deck
3. For a symmetrical bridge, the horizontal forces balance and large ground anchorages are not required.
4. Any number of the towers may be used. This type of the bridge can be as easily built with a single tower, as with a pair of towers
5. Cable provide elastic support to reduce the effective span of the decks

As a partially self balanced system is created, forces are transmitted in a relatively straightforward manner from the deck to the supports, producing a stiffer and more economical design.
Below are the practical examples of the cable stayed bridges found in the Greater Manchester:

Hulme Arch (1997) Parabolic Arch (Figure1 (a) and (b) )

Figure 1a

Figure 1b

Figure 2. *Trinity Bridge, Manchester, England. Spanning the canal and bridging the gap between Manchester and Salford.*

Figure 3. *Footbridge at the Manchester Piccadilly Station*

Reference:

1. Http://wikipedia.org
2. T. Ji and A. Bell- Seeing and Touching Structural Concepts
3. https://blackboard.manchester.ac.uk
4. www.maths.manchester.ac.uk

# 2.8 The Concept of Center of Mass in An Arc Floor Lamp

**Mohammad Bin Haji Abdul Karim**

The concept of center of mass plays a major role in stability of structure. Understand the concept and identify the location of the centre body of mass is essential for the stability of structures and also it may use to improve the structure stability (if requires).

When the centre of the gravity of an object is closer to the base, it will help to resists the object to overturn. However, if the centre of gravity is away from its base, this will cause the structure become unstable and possibly will overturn either due to horizontal force acts on the body or failure due to its base fails to balance the self-weight from the body.

Here is an example of the center of mass of a pyramid, if we take a look on the pyramid dimensions, it has a wider base (heavier at the bottom) and gradually decreases its dimension at top (lighter). The center of mass is located about 1/3 of height which closer to its base (figure 1a).

When the external horizontal force is applied to the structure (figure 1b), it shows that the center of mass of the body is still on the left of the structure. This will make the structure to return to its original position because of the gravity when the applied horizontal force is released (figure 1c). Thus, the lower the mass, the more stable to the body of structures.

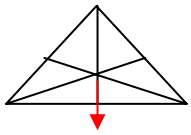


Figure 1a

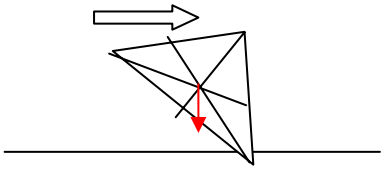


Figure 1b

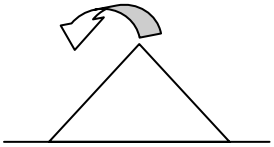


Figure 1c

**Practical Example 1 – An Arc Floor Lamp**

Figure 2. Arc Floor Lamp.

Obviously, the lamp will not standing as shown above if the center of body mass is acting on the lamp shade or the carving pole which is away from its base. The body will turnover due to the self-weight from the lamp shade and the pole.

Taking an example from the pyramid structure, the center of mass is close to its base and due to the wider dimensions on the base which make the pyramid is heavier at its base.

Thus the same concept is applied to the arch lamp, in order make the lamp stable the center of mass must be lower to its base. In this case, the weight at the lamp base is heavier where it can hold the lamp self-weight. This makes the lamp is stable and standing as shown above (Figure 2).

The examples below are some of high rise buildings and tower. It does not matter the shapes, height or inclined angle of the building structures, the concept of center of mass is still applied to make these buildings stable and reduce tendency of overturn.

Fig 3b. 30 St Mary Axe, London

Fig 3c. City Hall, London

This concept is also applied to other objects that require stability, such as follows:-

Fig 4a. Safety Cone

Fig 4b. Rubbish Bin

Fig 4c. Poster Stand

Reference:


- www.structuralconcepts.org
- Research Methods handouts – Tianjian Ji
- The figures were taken from Google image search engine for tall buildings, arc floor lamp, safety cone, rubbish bin, poster stand.

# 2.9 The Concept of Bracing & Direct Force Path

**Mohammad Bin Haji Abdul Karim**

The concept of bracing is used to make the structure stiffer and to transfer the force from the top of the structure to the foundation. This will reduce the redundancy of overturn and make the structure stable.

In building structures, the bracing is normally applied to high rise buildings or towers such as below:-

Fig. 5a. High rise building

Fig 5b. Electric Tower

Fig 5c. Electric Tower

From the figures above, it shows that the members are crossing each other to form bracing. The building will become stiffer and will maintain its forms from the lateral load such as winds.

The figures below will give some understanding how the bracing works;

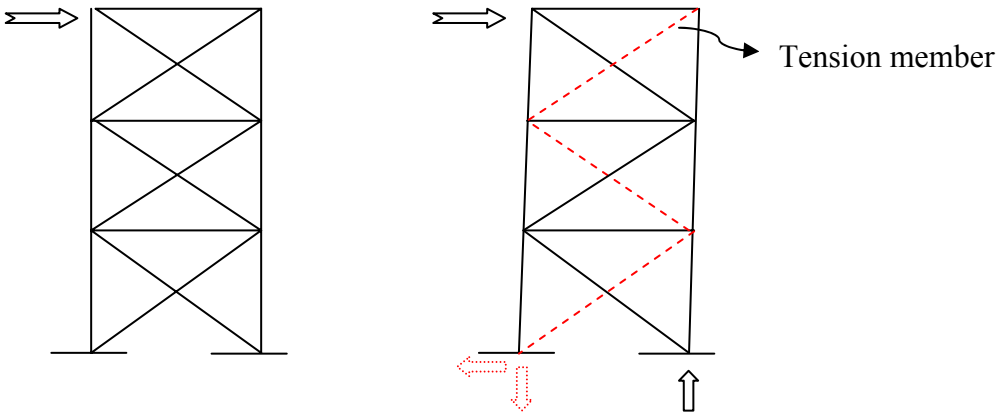



Fig 6. Free-body diagram of a braced building

From the figure 6 above, it shows the bracing members will act as tension (dotted lines) and others will remain as compression (continuous lines). When the lateral load, such as wind, push

from one side of the building, the tension members (dotted lines) will reduce the tendency of overturn and the load will transfer from the top to the foundation of the structure.

Thus the above concept will assists the structure to withstand the load such as winds and maintain its shape or form.

**Practical Example 2 – Gate Frame**

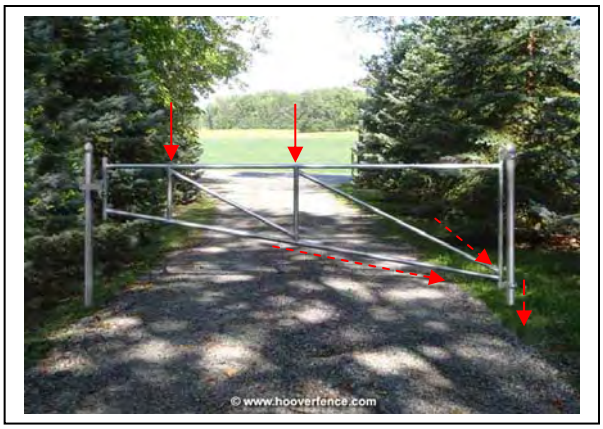



Fig 7. A Tabular Gate Frame

The bracing concept is also applied to the figure 7 above, a tabular aluminum gate frame. Due to the self weight from the top horizontal tabular member, the bracing is used to transmit the load from the top member (tensions) to the underneath members (act as compression) and transmit the load to the post which is buried firmly on the ground.

Some examples where bracing is also being used:-

Fig 8a. Tier Airer

Fig 8b An Iron board

Fig 8c. A Chair

Reference:

- www.structuralconcepts.org
- Research Methods handouts – Tianjian Ji
- The figures were taken from the following web address;
  - http://www.aplaceofsense.com/2008/08/bracing-is-beautiful.html
  - http://www.mikiemetric.net/ElectricTowers2.html
  - http://www.hooverfence.com/gatekits/barrier-gates/z-series.htm

- http://www.lakeland.co.uk/lakeland-concertina-airer/F/productimage/22194?returnURL=/lakeland-concertina-airer/F/keyword/airer/product/22194
- http://www.ecotoys.com.au/store/view-wooden-toys.php?toy=33
- http://www.promopeddler.com/world_famous/world-famous-counter-height-hardwood-director-chair-qqp239331.htm

# 2.10 Concept: Equilibrium

# Structure: cantilever roof

**Mohammad Hassan Mollazadeh (7737526)**

**Equilibrium** is the condition of a system in which competing influences are balanced.

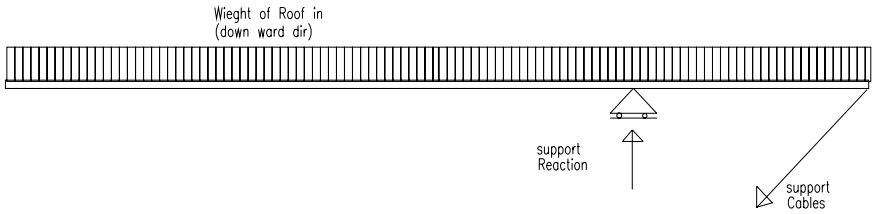
A body is in an equilibrium state when the sum of all reactions acting on a body is zero and also all moments about any point of a body is zero.

$\Sigma M = 0$
$\Sigma F = 0$

In the picture below the cantilever roof is in an equilibrium state by adding cable supports. This system is known as Tie system which creates stability for the cantilever roof.

*Guangzhou Olympus Stadium*
Fig.1 - Tie systems to stabilize the cantilevered roof

As you can see the cables are in tension, so they create bending moments against moments which is creates weight of roof on the left side, and also reactions acting on the roof are becoming zero. Therefore, we can see that roof is an equilibrium state.




**Free body diagram of roof**

Figure2 - Enlarged details of the Tie systems

Figure3 - Enlarged details of the Tie systems

**References:**

1. www.structuralconceps.com
2. Figures are from : *personal.cityu.edu.hk/~bswmwong/pl/pdf/**longspan**.pdf*

# 2.11 Concept: Span and Deflection

# Structure: Spring supports

**Mohammad Hassan Mollazadeh (7737526)**

Deflection of a beam is proportional to its span and load. The equation below shows the relationship.

$$\Delta = \alpha.q.L^4/(EI)$$

Engineers reduce the deflation of a beam in many ways. They increase the second moment area of a beam or add supports to reduce span (L).

One of the most effective ways to reduce deflections and increase the stiffness of a structure is adding supports. However, adding support may not be possible in every case and we usually have limitations in adding support. Therefore, we need add support creatively which can satisfy our limitations.

In a figure below you see a footbridge which is located in front of *Manchester Central*.

Fig1-Footbridge

In this structure, due to the effect of extra load at the end of the bridge, builders need to use three beams act as cantilevers to make the structure stiffer (Fig 2).

Figure 2

Thus, they need extra support for the beams. As you can see we have limitation here and it is not possible to add column under the beams, because of the road under the bridge. Therefore, beams were creatively reinforced with three cables, which are called spring supports. These cables support beams and make them stiffer.

Figure 3

References:

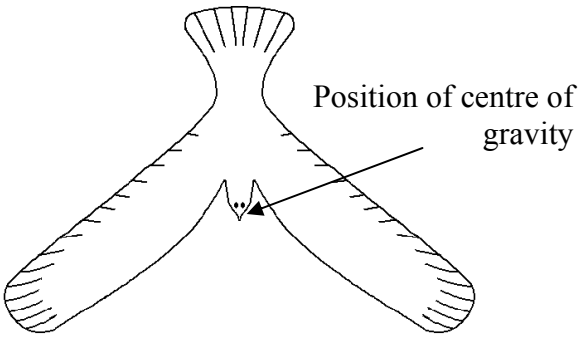
3. www.structuralconceps.com
4. Pictures are taken by my own

# 2.12 The Balancing Bird

**Muhammad Arifin Haji Ismail**

The balancing bird, is built based on the principle of gravity.

Centre of gravity / mass of an object is a point of location where the physical mass is concentrated. In the case of balancing bird, the mass is not uniformly distributed and the side wings of the bird being the heavier ends. Hence the centre of mass falls about the beak of the balancing bird.




Let your finger become the point of support and suspend the beak of balancing bird on the tip your finger. It will remain in stable equilibrium as it has tendency to rotate back to original position.

The stability of an object depends on the position between centre of gravity and point of support. If the centre of gravity is located above point of support, it will easily topple at any direction. As for the balancing bird, both of the points are at the same position which able to stabilize and prevent itself from toppling.

Nowadays, the idea of centre of gravity has been practically used by automobile makers to design much lower centre of gravity, giving better car handling and comfort. For instance, in a car race tournament, sport cars are modified with a lower height and strategically distributed the mass in order to reduce the risk of injury from toppling.

References:

http://schools.wikia.com/wiki/Center_of_Mass#Balancing_Birds
http://dev.physicslab.org/Document.aspx?doctype=3&filename=RotaryMotion_CenterMass.xml

# 2.13 Structural Concepts in Art - equilibrium of "Waterflowers"

**Órlaith O Brien**

## Introduction

Engineering and art are often considered to be polar opposites. Engineering is a very practical field whereas art is extremely creative. However, a perfect balance can be struck when art is inspired by engineering principals and vice versa. This is clearly evident in our surroundings and sculptures make for very good examples. They are aesthetically pleasing and can provoke debate or thought about a topic. On the other hand sculptures could also be described as small, unique structures which can be made out of materials commonly used in the engineering world.

Figure 1 – Waterflowers (photo from gilesrayner.com, 22/10/10)

## Sculpture details

One sculpture which I find to be particularly interesting is Waterflowers by Giles Rayner, as shown in Figure 1 above. It incorporates the fundamental laws of equilibrium and applies water as a load to produce a moving sculpture. At first the petals are in equilibrium in a horizontal. Water is then pumped up through the stem of the flower and down thin pipes into small buckets in the petals of the sculpture. As the petals fill with water they become heavier. The additional weight means that the forces in each petal are no longer balanced about their support. As the water continues to pump into the buckets the weight increases and the heavy buckets are forced downward. This continues until the petals are almost vertical at which point the water spills out of the buckets. Due to the decreasing amount of water the buckets become lighter and return to their original equilibrium until the whole cycle starts again. This process is explained in further detail below and illustrated in the Figures 2-4.

## Structural concept

The behaviour of the sculpture is clearly an application of the laws of equilibrium. Newton's 1st law states that "every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon" (Motte, 1729). Basically this means that an object will remain in a state of constant rest or uniform motion unless acted upon by an external force. It follows from this that if an object is static the sum of its forces must be equal to zero i.e. as it is not moving, no forces are acting on it.

$\Sigma F_x = 0;$
$\Sigma F_y = 0;$
$\Sigma F_z = 0.$

Consequently, this can be extended to rotational movement.

$\Sigma M_x = 0;$
$\Sigma M_y = 0;$
$\Sigma M_z = 0.$

These simple formulae can be used to explain the different stages of movement in the sculpture. At first, when there is no water in the bucket the petal is in a state of static equilibrium as it is stable. The sum of vertical forces equals zero as the downward force due to the self weight of the petal is counteracted by the reaction at the pinned support. As there is no rotation the moments about the support must also be equal to zero. However, this is less intuitive as the self weight of the petal is unevenly distributed due to the varying cross section. It is clear that the load due to the bucket is greater than the load due to the self weight of the material to the right of the support. It must be remembered though that Moment = force x lever arm and in this case the support is not at the midspan of the petal. The distance from the centre of mass of the bucket on the left to the support is much smaller than that of the petal. Thus the larger load of the bucket multiplied by the smaller lever arm is equivalent to the smaller load of the petal multiplied by the greater lever arm i.e. the petal is balanced.

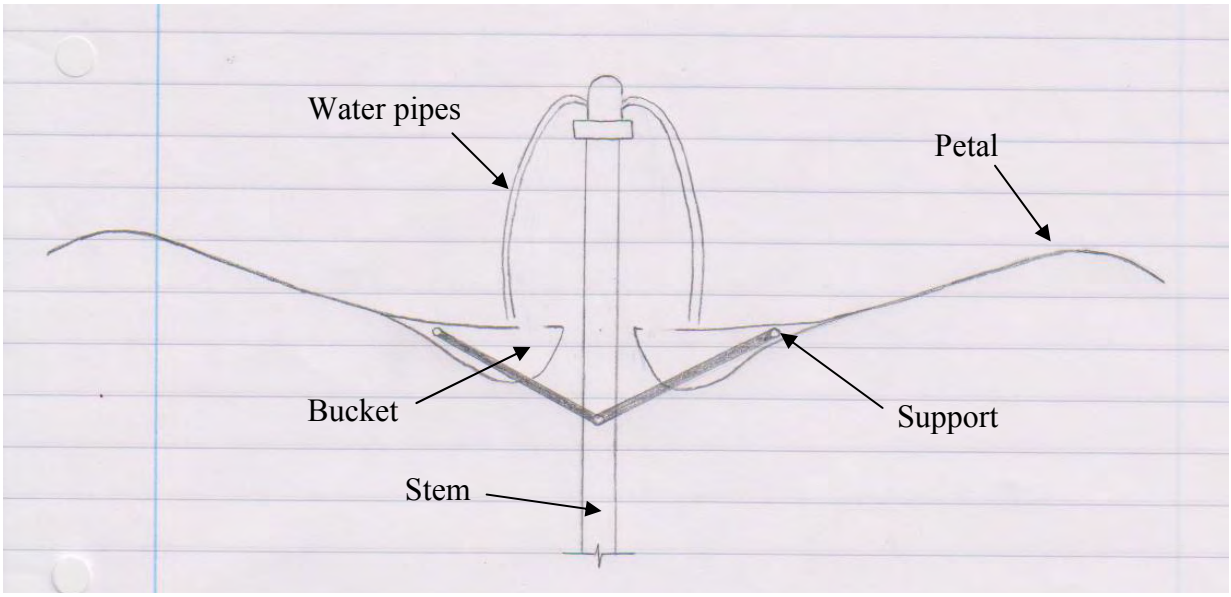



Figure 2 – Stage 1: Horizontal equilibrium

As the bucket fills with water the sculpture can be analysed in the same way except now the load due to the water must be considered as well as the self weight of the bucket. The moment due to the water

plus the bucket is larger than that of the petal and results in an anti-clockwise moment about the support. As it is a pinned support the petal is free to rotate about the support and as a result rotates in an anti-clockwise direction.

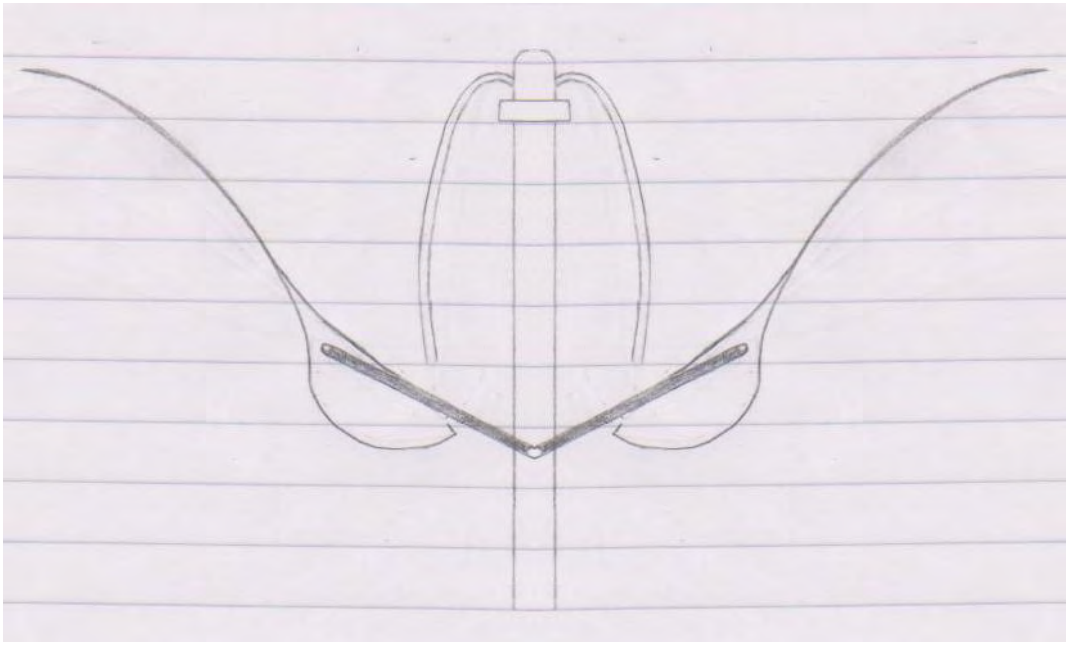


Figure 3 – Stage 2: Anti-clockwise rotation

As the water continues to fill the bucket the anti-clockwise moment increases until a point where the petal is vertical. The water can then no longer be contained in the bucket and begins to empty. As this happens the moment causing the petal to rotate decreases and the petal returns to its original position. At this point the bucket begins to fill with water again and the cycle repeats itself.

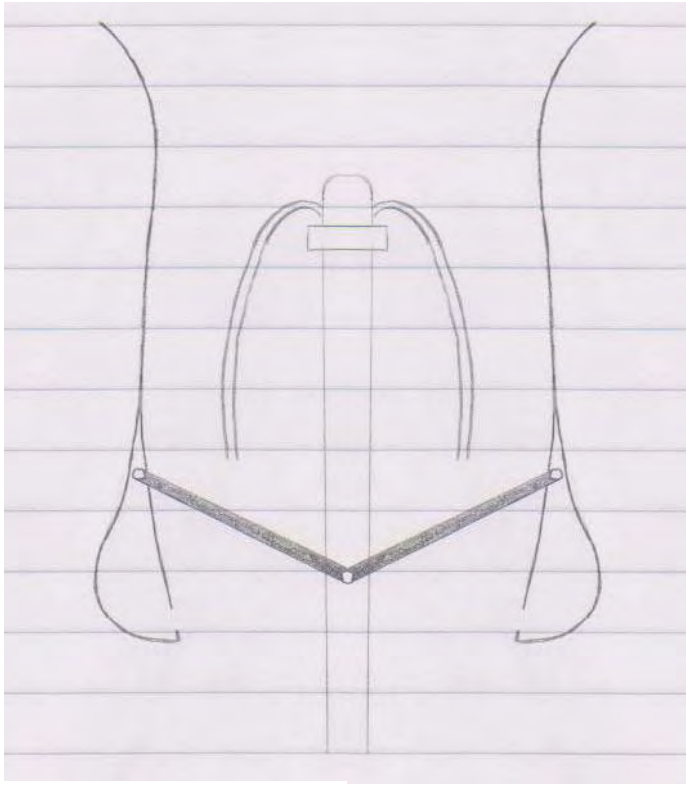


Figure 4 – Stage 3: Water emptying from buckets

Figure 5 – Close up of a single petal (photo from gilesrayner.com, 22/10/10)

**Conclusions**

The Waterflowers sculpture obviously utilises the equations of equilibrium in a creative, yet simple way. It incorporates both art and engineering and so is both aesthetically and logically pleasing. The constantly tranquil motion of the sculpture, as it moves in and out of equilibrium, has a very calming effect. This sculpture shows that equilibrium can be found between the imaginative and the practical to produce effortlessly elegant structures.

**References**

Newton, I., 1687. *The Mathematical Principles of Natural Philosophy.* Translated by Andrew Motte, 1729.

Giles Rayner, 2010. *Giles Rayner – Water Sculptor*. Available at: <www.gilesrayner.com> [Accessed 22 October 2010].

# 2.14 RESONANCE EXAMPLE: TACOMA NARROWS BRIDGE

Pedro Castro (7559851)

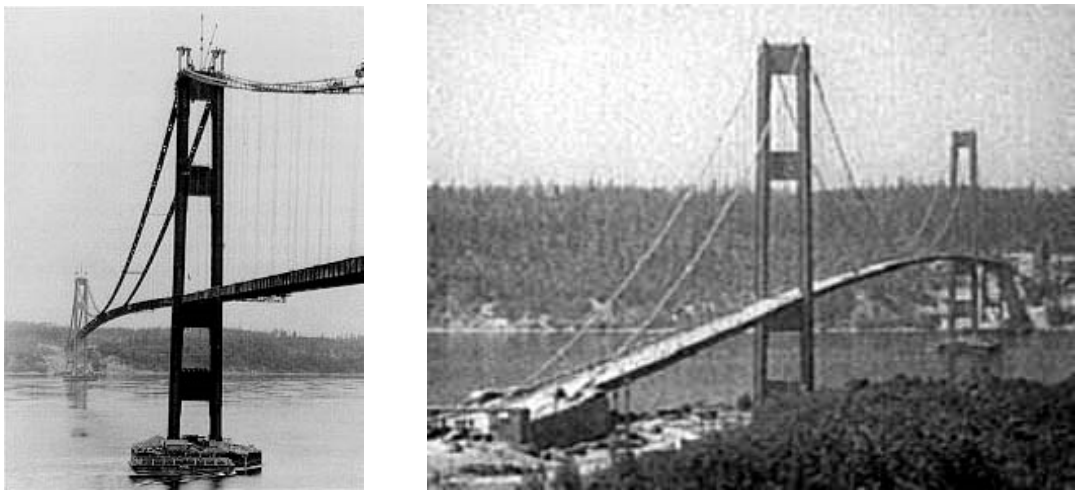


Figure 1.1. Tacoma Narrows Bridge [1.1]

The original and first bridge connecting Seattle to Tacoma was opened to traffic in July1, after two years of design and construction, and was called The Tacoma Narrows Bridge.It was the third longest suspension bridge in the USA at the time, with a leght of 1810meters including approaches and two supporting towers with 129.5meters high.

Although Tacoma Narrows bridge was one of the longest in the world it was also much narrower, lighter (its dead load was 1/10 of that of any other major suspension bridge) and flexible than any other at the time [1.2], that were based on trusses, arches, and cantilevers. The new bridge was built with shallow plate girders instead of the deep stiffening trusses (wind can pass through trusses and plate girders is an obstacle to the wind).

The low dead load coupled with the low dampening ability caused oscillation in the structure from the day of its opening which were caused by the wind.For this it acquired the nickname "Galloping Gertie."

On Thursday November 7, 1940 were initially there were winds of 56 Km/h that produced an oscillation in the bridge with an amplitude of 0.46m[1.3].The wind increased to 68 Km/h and the Structure started to vibrate with a frequency of 0.2 HZ [1.2].Sudenly the main font began to vibrate torsionally in 2 segments (figure 1.2 and figure 1.3) due the loosening of its collar in the north cable by which the roadway was suspended. The centre of the cable was moving back and forth relative to the centre of the suspended font. This allowed the structure to twist in two halves vibrating out-of-phase with one another.

The amplitude of torsional vibration quickly built up to about to 10 meters in each direction from horizontal and with a frequency 0.68 HZ [1.2], taken the structure to collapse shortly after 11 am. The wind velocity was close enough to the critical velocity for the torsional mode

observed, and the vibration built up by resonance and was maintained until collapse inevitably took place.(figure 1.4)

Some studies have concluded that the disaster could be avoid of many ways such as:

- Use open stiffening trusses which would allow the free passage of the wind;
- Increase the stiffness and depth of trusses or girders;
- Increase the weight of the bridge;
- Dampen the bridge;

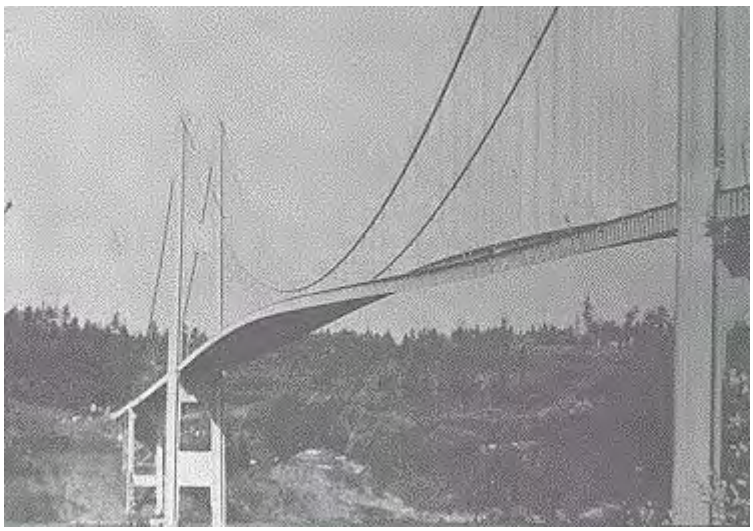


Figure 1.2. Torsional Mode of the Tacoma Narrows Bridge[1.3]

Figure1. 3.Torsional Mode of the Tacoma Narrows Bridge[1.3]

Figure 1.4. Failure of the Tacoma Narrows Bridge[1.3]

Ponte.WMV

Video 1-The Tacoma Bridge disaster [1.5]

REFERENCES

1.1 http://www.engineering.com/Library/ArticlesPage/tabid/85/articleType/ArticleView/articleId/171/Tacoma-Bridge.aspx
1.2 http://matdl.org/failurecases/Bridge%20Cases/Tacoma.htm
1.3 http://www.vibrationdata.com/Tacoma.htm
1.4 http://www.enm.bris.ac.uk/anm/tacoma/tacoma.html
1.5 www.dec.fct.unl.pt
1.6 http://www.math.harvard.edu/archive/21b_fall_03/tacoma/index.html

# 2.15 RESONANCE MODEL -PENDULUM

Pedro Castro (7559851)

Resonance: "A condition in which a system vibrates with maximum amplitude.When the frequency of the exciting force coincides with the natural undamped frequency of the system"[1.7]

I have decided as well, to make a model demonstration of the resonance phenomenon.To do that i use a piece of rope (figure.2.1), a piece of paper (figure.2.2) that i have crush (figure.2.3) and with both i have done a pendulum(figure.2.4).

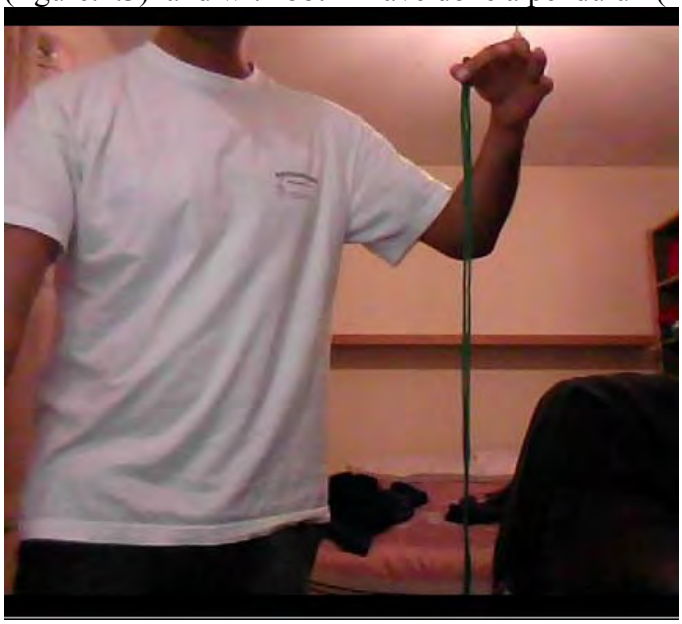


Figure 2.1. Piece of rope

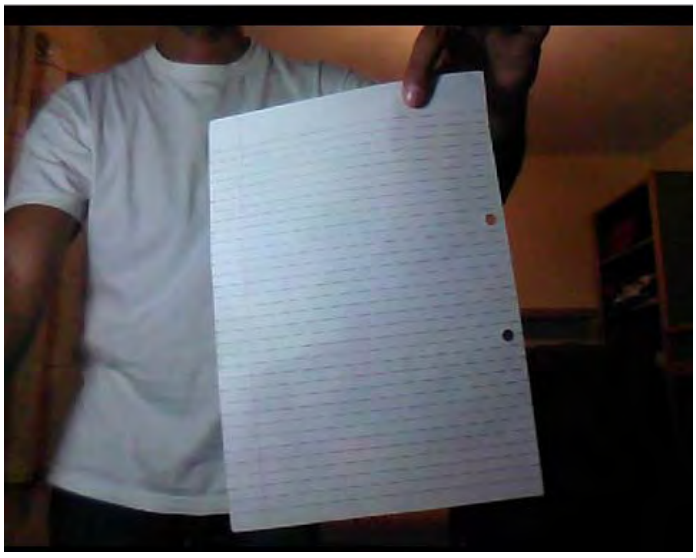


Figure 2.2. Piece of paper

Figure 2.3. Paper crush

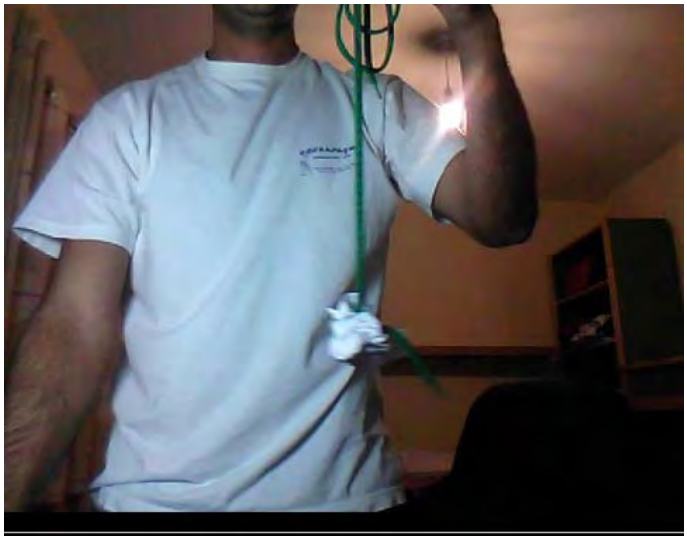


Figure 2.1. Home made pendulum

The dynamic phenomena can be explained qualitatively as follows:

- The person holding pendulum will blow the piece of paper, creating a situation where the frequency of the blow is much smaller than the natural frequency of the pendulum. It will be observed that the amplitude of movement of the piece of paper (mass) is almost the same as the blow.
- when the person blows at a frequency close to the natural frequency of the system, a situation is created in which resonance develops. It is observed that the movements of the mass are much larger than the blow.

REFERENCES

1.7 Blockley, David., (2005), New Dictionary of Civil Engineering, Pinguin Reference, pp.385.
1.8 www.structuralconcepts.org/

# 2.16 Hanging heavy weight on ceiling

**Rajesh Thomas Vaidyan**

When a heavy weight like fan, lamps, etc hangs on the top of a room, it carries the whole load of hanging the hook and the loads at the point it is hooked. But if it was a pointed load, the structure at the point would have collapsed due the high stress at the point (since high load acts on a small area). But on the ceiling, the hook is designed with longer arms on it such that the load doesn't act at a pointed end but the load is transferred horizontally to the length of the arms, and the stress concentration gets reduced and the load remains safe at the end. Some figures of the hangings on celings are shown.

Some hooks used on the ceilings, which has either wider area on the top end or with side arms to distribute the loads are as shown in the figures below..

These have higher area at the top which helps to reduce the stress acting at a point, and transfers to a wider area and hence helps to endure more loads on the hooks to be hanged on the ceiling.

**Structural concept**

The stress gets reduced when the area at which the load acts increases.

# 2.17 Nature- Engineering connection TAIPEI Tower 101

**Issa Socrates**

Taipei 101 one of world's largest towers spanning 508 meters above the earth but Taipei 101 is not just that it is a landmark to high tech engineering and construction, using simply principles of nature rather than smart technological up to date systems. Taipei 101 had to be design to withstand two of nature's catastrophic forces earthquakes and wind loads, when attempting to design a building of this size things can become rather complicated, it is worth mentioning at this point that Taipei 101 is the first building of this size to be built on a seismic area. Another drawback that the engineers had to deal with was the inhospitable ground conditions of the Taipei city, a layer of soft clay made things even more difficult for the design of the foundations. For the tower to be built engineers had to seek for answers from the power of the earth hence they had to design a building that was flexible enough to withstand the large scale earthquakes and in the same time be stiff enough to withstand the heavy wind loads, a concept that was never put into practice before at this size.

The first inspiration of the engineering that came from nature was the shape of the building and way of construction. Now it is pretty much noticeable that most skyscrapers round the world are pretty much box like building the Taipei tower though it stood out in matters of design for its time since it rises from the ground like a bamboo shoot, and the similarities do not stop there the building was divided into sections like the bamboo shoot so each section acts as an in depended unit this pushed the gravity load inwards the center of the mass of the building rather than outside. The result was a stronger, lighter and more flexible tower. The Taipei tower was design to be the joule of the city therefore architects had but all of their effort in making it one by giving each section the form of a Chinese pagoda as their form, also lucky number eight, which means blooming or success, is represented by the eight exterior sections of the building.

Taipei 101 was without dough one of the most challenging engineering works especially when geological investigation was launched to the site at the begging of construction in 1999 proving that the building site was only 200m away from a huge fault, now the closer a building is to a fault the bigger the impact on the building these chanced things the building must be designed to withstand devastating earthquake forces acting vertically and horizontally. Earthquake loads can be become very tricky because most of the times are unpredictable and engineers lack in understanding their behavior nevertheless there impact on a building of this size can be brittle.

To withstand these massive loading the engineers came up with a rather regular approach to the solution they designed a complex internal mega structure that could resist the loads. The structure was made up of a central core that was connected to eight incredibly strong columns the connection was made using a network of horizontal trusses. This internal structure was working like a giant flexible spine allowing the building to flex and move but not to break, but the tricky part of the building comes only later.

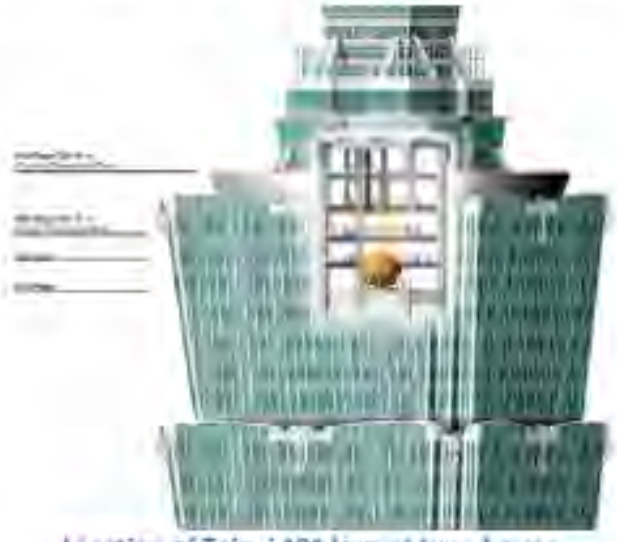
Massive earthquake loading was not the only issue here as stated above the building was also suffering from heavy wind loads, wind loads recorded in the area could reach speeds of 200 km/h but for a building of this size even a small breeze can make the occupants of the building to feel it. This kind of buildings act as swings more or less, for the swing to move your mass it is necessary to move your legs to create energy then for this kind of tall building a small breeze can provide the movement and the mass of the building can start to swing making it extremely dangerous. The usual solution to this problem is to create a stiff structure and here is where the controversy begins for the earthquake load stiff can cause brittle failures therefore a more flexible structure is required and then at the same time to resist wind loads the structure must be stiff. For the project to go ahead a solution must be found to withstand both conditions.

Engineers to resume with the problem came up with several ways of approaching the problem firstly the shape of the building was used to reduce the wind loads according to the shape the engineers could make more saw tooth like corners which proved to reduce the wind loading from up to 30-40%. The reduce was pretty good and effective but these corners did not get rid of the wind, the wind was only redirected on the building so to go back to the swing when you are not moving your legs each movement adds energy to the system when your legs are stable there is no movement but there is still energy in the system, the same applies for buildings even though the wind is reduced energy will continue to gather unless it is removed. After all is not the push that provides the movement on the swing is the repetitions the engineers took this relation and though that by finding a way of canceling the movement or even minimizing it then the building might reach its level of strength and stability after all, so the big task was to find a way to stabilize the building.

In order to resolve such problems nowadays engineering has a lot of complicated software's that can control the sway and swing of the building but in the Taipei tower engineers when for a more passive approach coming from the 1600 from Galileo the well known pendulum, but never underestimate the Taipei towers approach they took the simply pendulum and convert it into a complex mechanism that could finally stabilize their building and give it the rigidity required.

The pendulum in the 101 tower is basically a Tuned Mass Damper (TMD) which is suspended by cable from the 92nd floor to give the Damper appropriate natural period of vibration, It consists of a 650-ton sphere, made of stacked steel plates, this simple passive system is reliable, requires minimum maintenance and proved to be adequate solution to the problem basically an idea derived from hundreds of years ago proved to give a solution to a major nowadays problem.

The way the tuned mass dumper works in the 101 tower is pretty simple the 650 tone sphere acts as a counter weight to the wind motions, so basically when the wind causes a sway to the building in one direction the sphere will move in the other direction to minimize the movement of the building the motion of the sphere can cancel the built up energy and reduce the overall motion.



Location of Taipei 101 largest tuned mass

Movement of the building and sphere

Even though it sounds as simple as that to put it into work was a complicated task and the whole system is much cleverer and sophisticated as it first looks. The 650 tone sphere is hanged from the wires at level 92 but it is not jest hanged the sphere sits on a set of hydraulic jacks. The hydraulic jacks act as the regular shock absorbers of your every day car. Basically what the hydraulic jacks do is the same as what they do in the car they control the dumping and the excessively movements of the sphere making sure that the sphere never pushes too much and never too little. There role is relatively significant also in cases where the building may experience a sudden movement such an earthquake where the building will say suddenly the sphere must stay in the middle and not move to a direction

that could work against the stability of the overall structure, for this problem the answer was lying in an invasion that was made hundreds of years ago the shock absorber.

To sum up with the Taipei 101 tower is an engineering proof that when nature prevents some things from happening at the same time it provides you with right tools to beat it and with this engineering project the engineers have proved by using simple principles of life and engineering concepts that it can be done and when it does a great outcome is revealed. And the proof is standing 508 meters in the center of Taipei city being the diamond of the city to some people and for us an engineering art that changed engineering rules and regulations because when everything was pushing this project to the bin the engineers made it work and stand out.

Issa Socrates

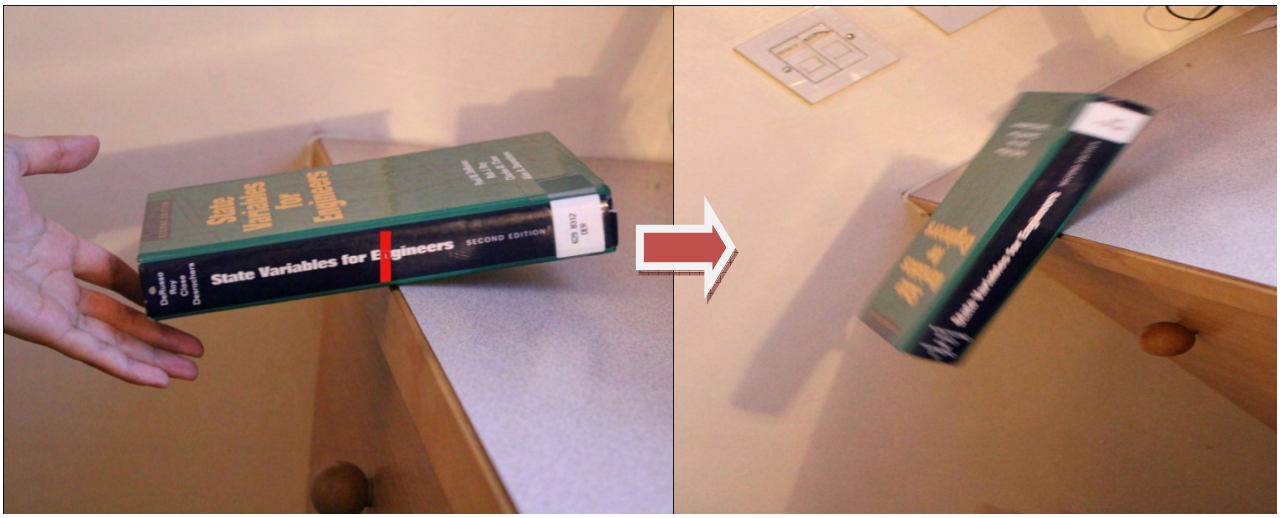
# 2.18 Overhang Structure

**Tiarma Octriviani**

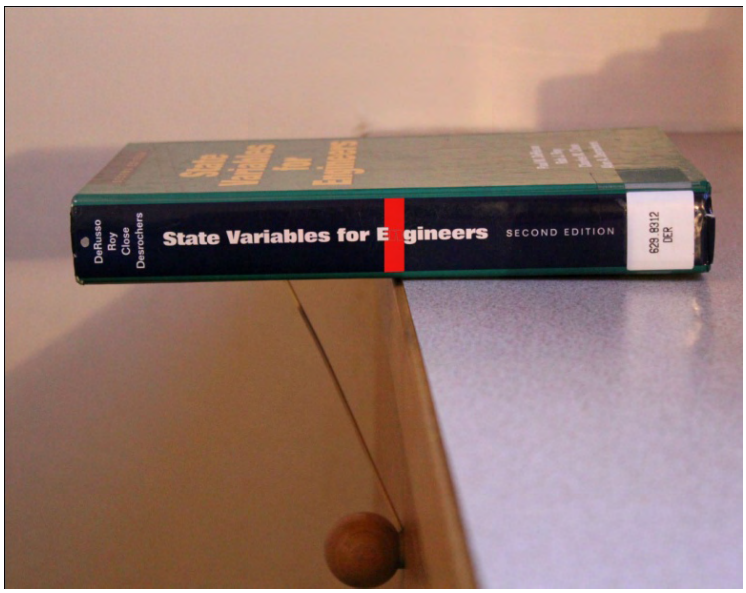
## Description

Overhang is a part of structure beyond the wall of lower part. Over hang usually formed at roof of building. This demonstration shows the overhang structure which was supported by buffer could subjected higher load.

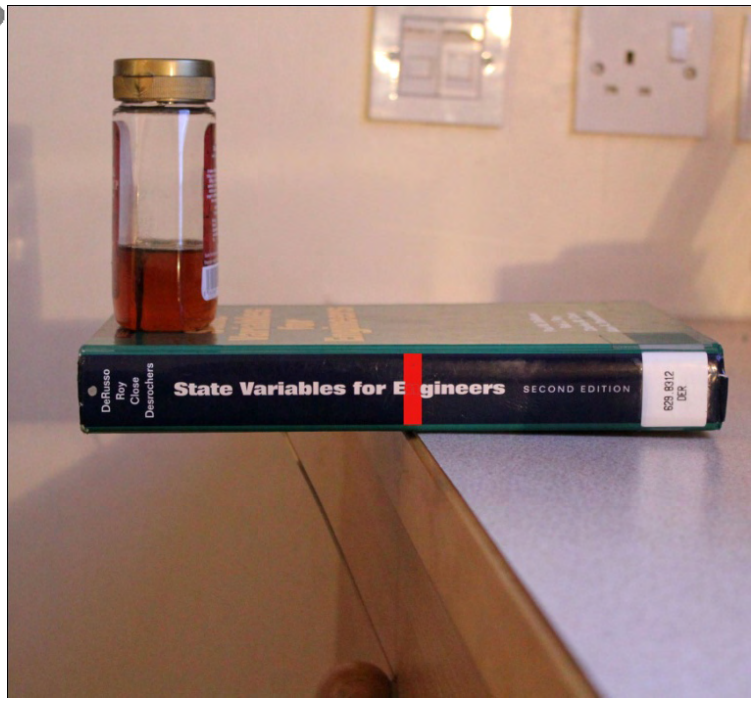
This experiment included book as beam, a wooden stick as a supporter and a bottle of jam as load.




Picture 1:
Put the book on the table, the red line in the book was adjusted to the edge of table. Without buffer to detain the book will drop suddenly.



Picture 2 :
Setting up the experiment as the picture 1and also put the the stick as support in this model. Stick was utilized to resist the book to avoid it from collapsed.




Picture 3:
The bottle of jam in the picture shown above can be additional load which was applied on the book. It can be seen that stick can resist load both of book and bottle.

**Structural Model**

In practical sample, overhang structure in the picture below can be a shading overhang window. It was formed by additional roof which supported with wooden girder. This window was formed not as a cantilever which mean the additional roof supported only with wooden girder, there wasn't beam to resist moment and shear stress. Nowadays, Overhang usually be slab extensions and constructed with cantilever beam under slab extensions, light weight material can be used for overhang structure but exceed vertical load can cause collapsed for structure.

**References**

1. The Jhon Rylands University Library,The University Of Manchester http://www.sciencedirect.com/science
2. http://www.builditsolar.com/Projects/Cooling/Shading/Shading.htm

# 2.19 Centre of Mass Used in Sharp Bottomed Amphora

**Wen Jiang (72129033)**

A sharp bottomed amphora is used in ancient China (Banpo phase of Yangshao culture). When putting the amphora into water, the amphora will stand up automatically in the water with a full amphora of water. Then the user could pull the amphora out of water by the tie through the two rings on both sides of the amphora.

Picture 1

The structural concepts related to using the amphora is the centre of mass.

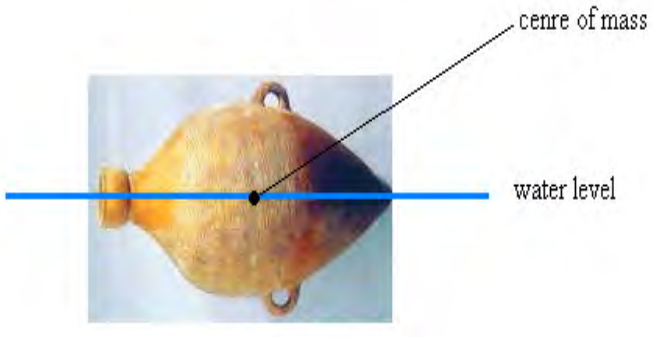
Centre of gravity is the point on which the gravity force affects under an equilibrium situation, but if this body is smaller enough when compared with earth, the centre of gravity of this body could be described as same as the centre of mass of this particular body.

Due to the gravity force, a body will always move to a position which could lead the centre of mass to a lower location that will also make the body more stable.

In this case, the amphora will move as the water fills in, because as water keeps moving into the amphora, the position of centre of mass will keep changing, so that the body itself will move due to the gravity force.

A description of the whole water gathering procedure is given.

Step 1: putting the amphora into the water resource that to be gathered.




Picture 2

As the amphora is symmetric, the centre of mass must be on the symmetrical axis, when dropping the amphora into water, the amphora will be floating on the water level.

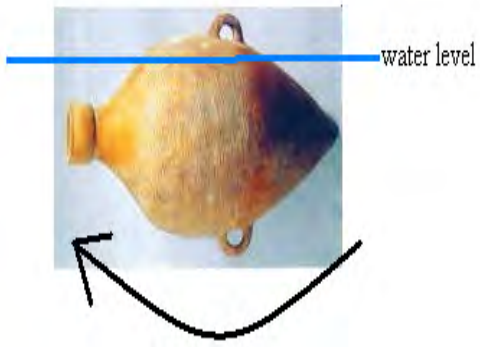
At the beginning, the amphora is empty, but as half of the water entering hole is below the water level, water could enter to the amphora due to water pressure.

Step 2: Water goes into the amphora and the amphora will move downwards.

As water flows into the amphora, the gravity force of the amphora will increase, so the body will move downwards into water, and then more water will flow into the amphora and a further downwards movement will carry out.

During the downwards movement of the amphora, all the space within the amphora that under the water level will be filled with water.

Step 3: The amphora will turn automatically when it is full of water.

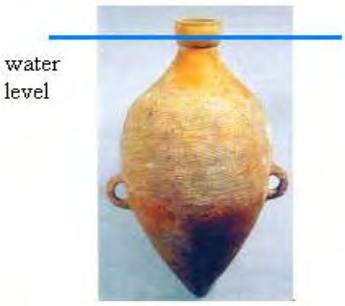



When water is almost full in the amphora, the centre of mass will move to the right rather than stay in the same location as the mass of water in the amphora will change the distribution of mass all along the body. And the mass distribution will continue changing during the procedure that water keeps flowing in.

Once the centre of mass moves to the right, it means that the affecting point of gravity force will move to the right. In this case a bending moment will occur that turns the amphora in the clock-wise direction.

In the turning process, the water will flow to the bottom of the amphora as a result of gravity force. This will cause a further right-wards movement of centre of mass as well as a greater bending moment caused by gravity force.

Step 4: The amphora finally stand in the water.




After the amphora is filled with water, the location of the centre of mass of the whole body will not change any more, so the body will be stable in the water, with top over the water level and other parts below the water level. Then the amphora could be gathered from the water resource with full bottle of water.

In this way water is gathered.

References:

All pictures are from *http://www.guimet.fr/Jiandiping-amphora*

A related video clap from *http://v.youku.com/v_show/id_XNTI0NDM4Njg=.html*

# 2.20 Understanding Simple Truss by Analysing Store Display Hanger

**Willy William**

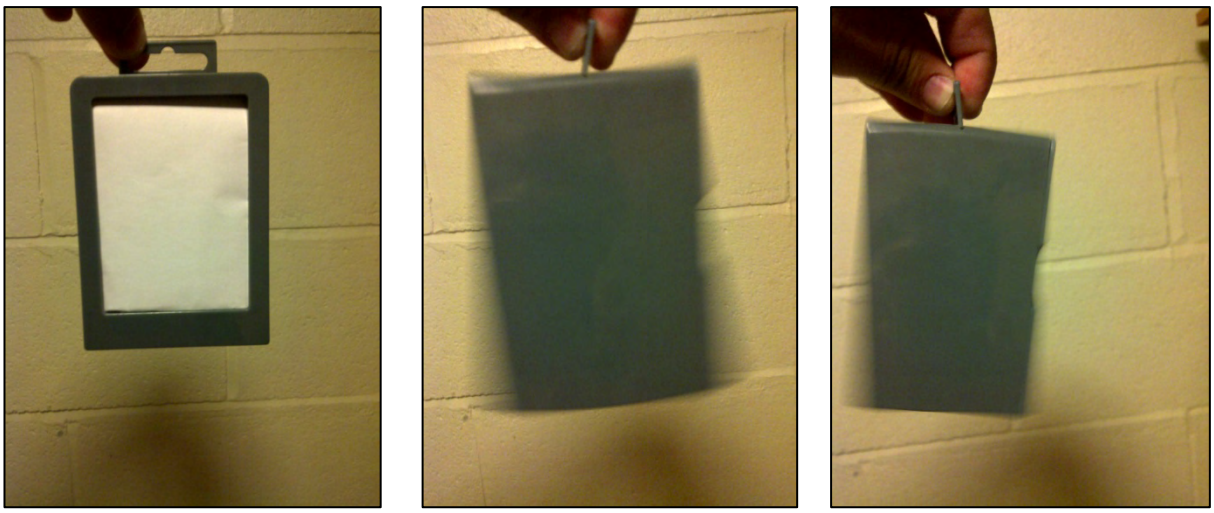
## Introduction

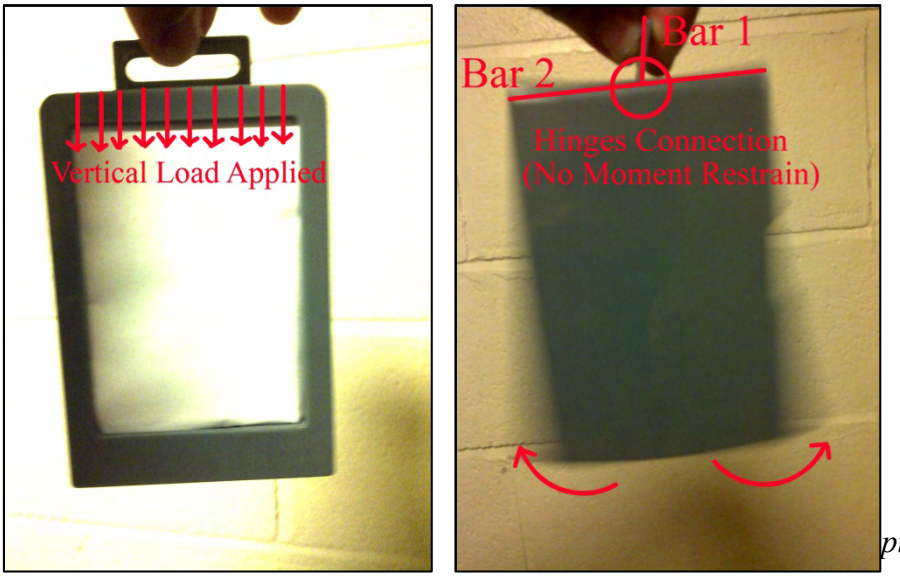
I was trying to understand a structural problem related to our daily life and finally i found one thing which can be used as an example. I went to one of store in Manchester, and came out with a simple idea, 'Store Display Hanger'.

It is a thing which is usually used to display merchandise in store. I decided to use watch display hanger.

## Explanation

I tried to use display hanger for watches which is shown in pictures below. A connection of small part of hanger above the box is the hinges connection. It can be rotated and causing the box swing to the horizontal direction.



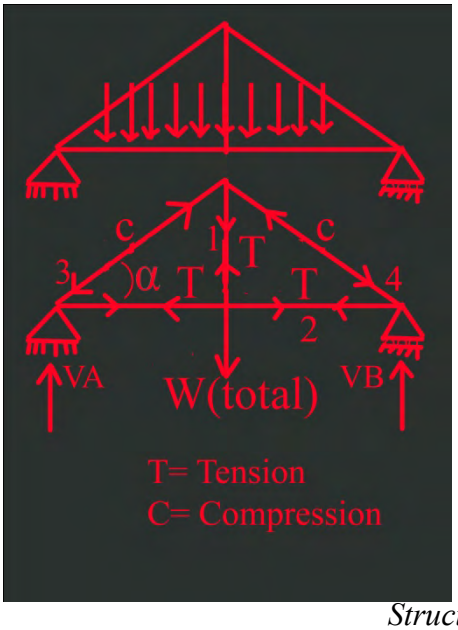


As we can see above, box located below the hanger can express the load working on the bar. The connection between hanger part (bar1) and box (bar2) below is called hinges connection which doesn't have any moment restrain on it.

Hinges connection allow bars to rotate either clockwise or anti-clockwise depends on the load works. Figures shown above are not stable structure system, therefore we need to add some bars to equal the load applied on each joint and bar.

I put additional bar using short rope which is tied up at each corner. This additional part will effect the system become stable. Hinges joint between bar1 and bar2 become more stable and can't be rotated easily. We can analyze this system as a truss system which is commonly used in bridge, tower, and roof structure system.

There isn't any moment forces work on the members, however the axial load working on each joint have to be equal. After the equilibrium on each member achieved, the structure will become stiffer and able to bear applied load.



If we analyze the equilibrium of the structure above and we take the left restrain as A , on the other hand the right restrain as B, the equilibrium equation on the A can be calculated as:

$$\sum VA = 0$$

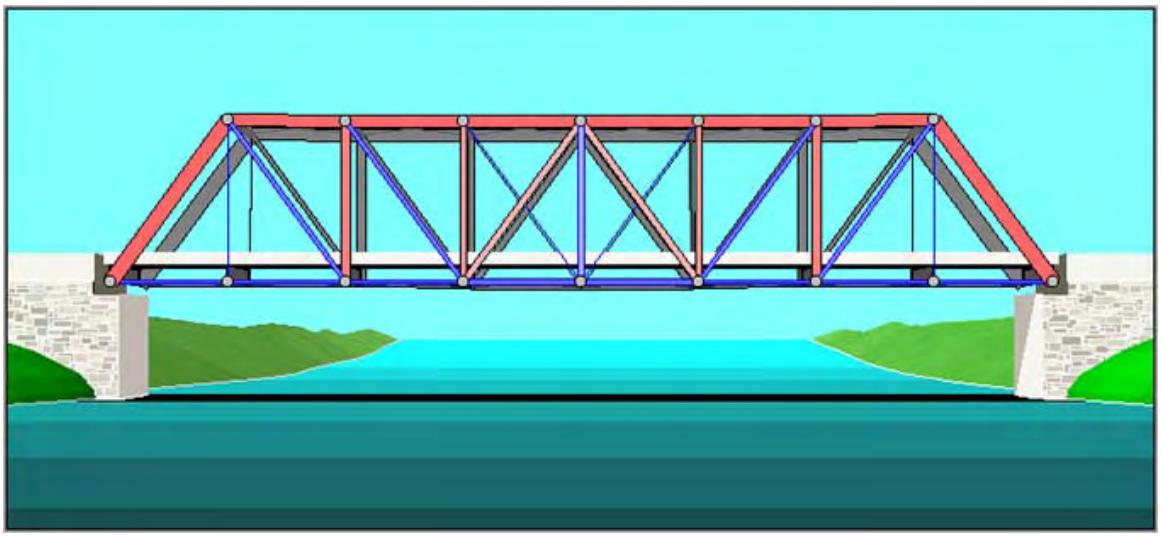
$$VA - F3\sin\alpha = 0$$

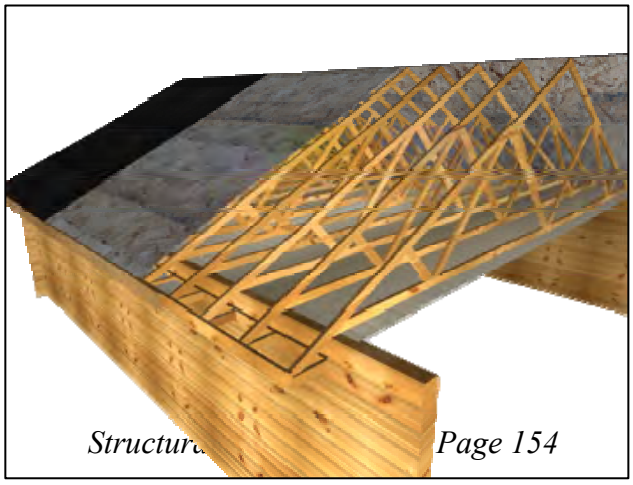
$$\sum HA = 0$$

$$-F3\cos\alpha + F2 = 0$$

From the equilibrium above, we can gain the value and direction of forces working on each member. There are two direction of axial forces, tension and compression. This equilibrium will stabilize the system of the structure.

**Practical Examples**





# 2.21 Calculation of Membrane Structure simulation

**Xiaoqing Yu 7690662**

## 1. Introduction and question

### *1.1 Introductions to the membrane structure*

Membrane structure is the mid-20th century developed a new type of architectural structure, is a combination of high strength thin film materials (PVC, or Teflon) and the strength member (steel frame, steel columns or cable) through a certain way to some extent within Pre-tensile stress to form the shape of a space, as the cover structure, and can withstand a certain degree of external loading of a spatial structure.

As the membrane material it is not compressive and flexural stiffness, the rigidity and stability required by changes in membrane surface curvature to improve on the membrane structure. So the shape of the final film surface must satisfy certain boundary conditions, certain conditions, the mechanical balance of pre-stress, and a benchmark for analysis of load analysis and cutting.

The core issue for a membrane structure is to define its shape when it is under a certain pre-stress. To find the shape is to find the displacement. If the calculation is enough, the simulation will be very accurate.

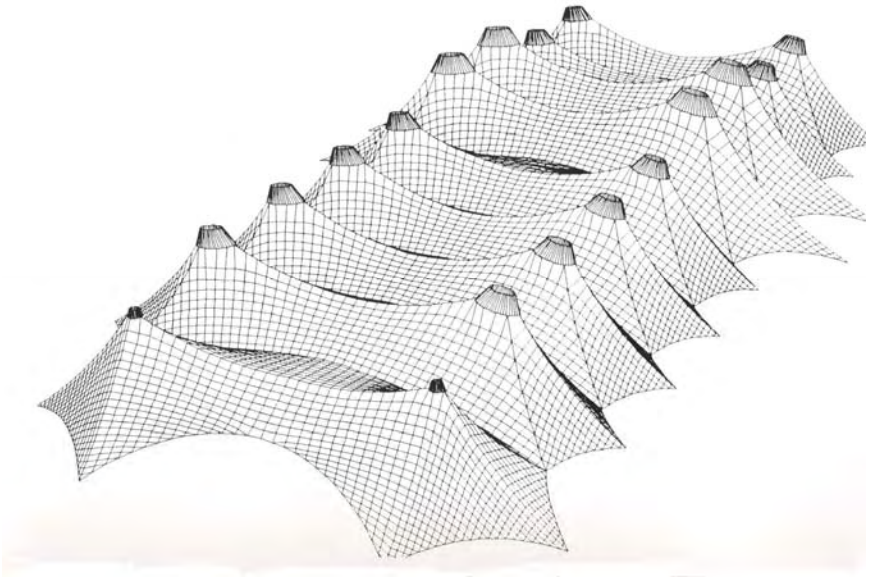
For a general load case, the surface of membrane can be emulated (by software such as MATLAB, ANSYS) as a network of reinforced cables. So the equilibrium for each node is formulated as

$$\sum_{i=1}^{St} F_i - F_{jext}$$

*for j= 1,…,n*

- *n*= the number of nodes
- *St*= number of elements which is connected to node j

Night View of Denver International Airport

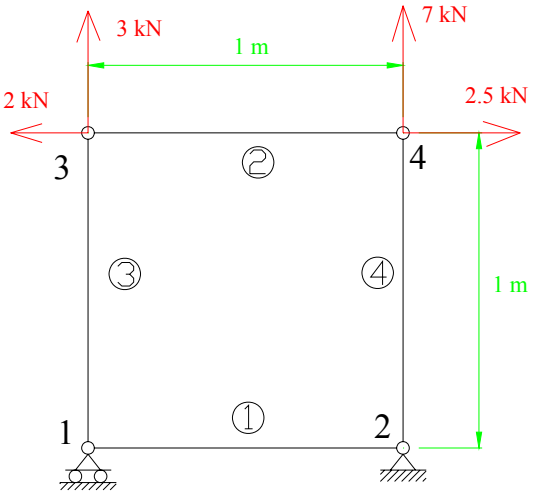


Simulation for the roof of the Denver International Airport

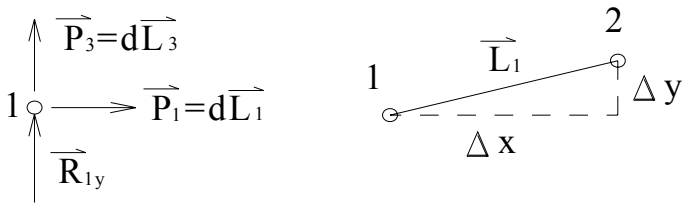
### *1.2 Question*

So for a shown example below a 4 nodes and 4 joints structure, find the nodal displacement and each node (This displacement can be used for accurate the membrane shape under certain pre-stress, this is only a numerical example, for this emulation and calculation is done by the complex computer program).

## 2. Solution




For Node 1, the loading analysis is shown in figure below




*Force analysis of node 1*

*d is called force density, the term above is for general load case, here set is as 1.

From the figure, it can be seen

$$\Delta x = x_1 - x_2$$

$$\Delta y = y_1 - y_2$$

The force equilibrium gives: $\begin{cases} P_{1x} + P_{3x} = 0 \\ P_{1y} + P_{3y} = R_{1y} \end{cases}$

$$\begin{cases} d(x_1 - x_2) + d(x_1 - x_3) = 0 \\ d(y_1 - y_2) + d(y_1 - y_3) = R_{1y} \end{cases}$$

$$\begin{cases} 2dx_1 - dx_2 - dx_3 = 0 \\ 2dy_1 - dy_2 - dy_3 = R_{1y} \end{cases}$$

Similarly, for nodes 2, 3 and 4:

Node 2:

$$\begin{cases} -dx_1 + 2dx_2 - dx_4 = R_{2x} \\ -dy_1 + 2dy_2 - dy_4 = R_{2y} \end{cases}$$

Node 3:

$$\begin{cases} -dx_1 + 2dx_3 - dx_4 = -2 \\ -dy_1 + 2dy_3 - dy_4 = 3 \end{cases}$$

Node 4:

$$\begin{cases} -dx_2 - dx_3 + 2dx_4 = 2.5 \\ -dy_2 - dy_3 + 2dy_4 = 7 \end{cases}$$

Hence, the total equation in matrix form is:

$$\begin{bmatrix} 2 & 0 & -1 & 0 & -1 & 0 & 0 & 0 \\ 0 & 2 & 0 & -1 & 0 & -1 & 0 & 0 \\ -1 & 0 & 2 & 0 & 0 & 0 & -1 & 0 \\ 0 & -1 & 0 & 2 & 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 & 2 & 0 & -1 & 0 \\ 0 & -1 & 0 & 0 & 0 & 2 & 0 & -1 \\ 0 & 0 & -1 & 0 & 1 & 0 & 2 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 & 2 \end{bmatrix} \times \begin{Bmatrix} x_1 \\ y_1 \\ x_2 \\ y_2 \\ x_3 \\ y_3 \\ x_4 \\ y_4 \end{Bmatrix} = \begin{Bmatrix} 0 \\ R_{1y} \\ R_{2x} \\ R_{2y} \\ -2 \\ 3 \\ 2.5 \\ 7 \end{Bmatrix} \quad \text{where} \quad \begin{aligned} y_1 &= 0 \\ x_2 &= 1 \\ y_2 &= 0 \end{aligned}$$

By solving equation we can get the final coordinates of the nodes as

$$\begin{Bmatrix} x_1 \\ y_1 \\ x_2 \\ y_2 \\ x_3 \\ y_3 \\ x_4 \\ y_4 \end{Bmatrix} = \begin{Bmatrix} 0.625 \\ 0 \\ 1 \\ 0 \\ 0.25 \\ 4.333 \\ 1.875 \\ 5.667 \end{Bmatrix}$$

# 2.22 Seeing and touching Structural Concepts: ARCHES

**Clive Bhebhe 7667647**

Arches where developed during the Roman Empire. They were an engineering solution used by Roman architects/engineers to design castles, temples etc. In hey days arches then became a major solution to rail and road travel across Britain allowing bridge construction across canals and valleys. Most railway station roofs across the world were then designed using joined convex shapes allowing longer spans to accommodate the large size of locomotives. Lately arches have been a major influence to some of the most iconic engineering structures e.g. the London stock exchange (fig 1.1 shown below).

Figure 15.1: London Stock Exchange

Arches are circular spans that are very good in sustaining compressive forces mostly when used with masonry. They are however efficient with other material structures such as steel trusses. The historical success of arches is based on an understanding of the structural advantage, the use of compression in dealing with loads and stresses. The aesthetic appeal is based on flexibility related to form. A masonry arch can take on a variety of shapes, all the while responding to balance, proportion and scale in design. The arch's great resistance to compression makes it the most efficient structural element in dealing with spanning openings.

Arches have been historically constructed with unreinforced masonry. In an unreinforced state, the masonry arch has been used to span various size openings and across considerable lengths. Due to the curvature characteristics of the arch design, it provides great structural efficiency that successfully transfers vertical loads and vertical forces. This can be demonstrated by the foot skeletal structure (fig1.2). Because of the bone's compressive strength, the foot arch can support considerable load.

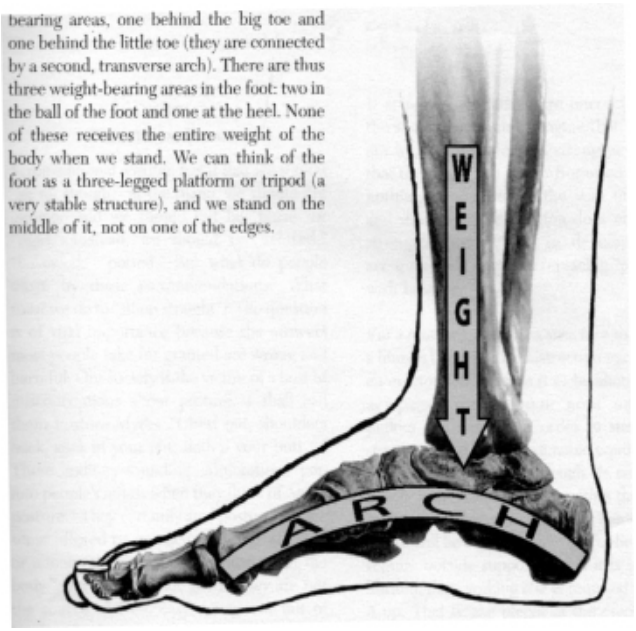
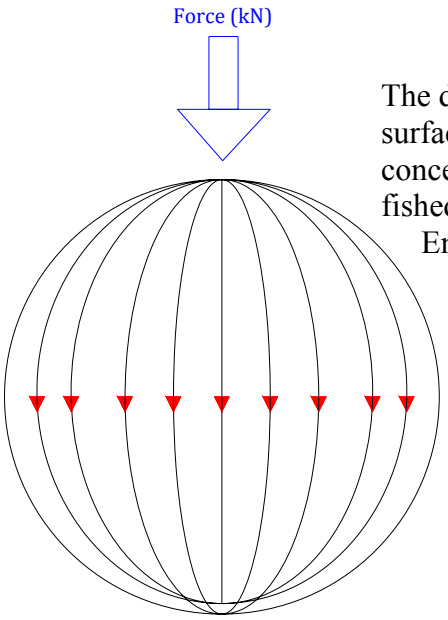

bearing areas, one behind the big toe and one behind the little toe (they are connected by a second, transverse arch). There are thus three weight-bearing areas in the foot: two in the ball of the foot and one at the heel. None of these receives the entire weight of the body when we stand. We can think of the foot as a three-legged platform or tripod (a very stable structure), and we stand on the middle of it, not on one of the edges.
WEIGHT
ARCH

Figure 1.2: Foot skeletal structure

However, while history points to hundreds of masonry-only examples of arch construction, today we are seeing a combination of materials. An everyday example of the arch performance is identified with the egg shell. Shells are particularly efficient structures being rigid and lightweight, the curved surfaces can be very thin allowing more space for the embryo. The inner space is beneficiary when implementing the design to a real life structural concept. Curved

surfaces distribute loads evenly across the surface area of the structure making them rigid and stronger. Using a single egg, I got it subject to a compressive force as shown in the diagram below. The resilience is quite unexpected showing an enormous structural strength in one axis yet so fragile in the other.

Figure 1.3: Egg subjected to crushing force.




Stress Distribution In a Circular Structure

The diagram below shows the distribution of forces along the surface area of a circular object. Video evidence of the egg concept has been submitted with this report. This video was fished out from a National Geographic TV programme "Extreme Engineering".

**Bibliography**


- Figures 1.2 and 1.3 were taken from goggle
- Video was taken from National Geographic

This booklet is a collection of students' coursework on, "Enhancing the understanding of structural concepts", which is part of the module Research Methods in 2010-11 at The University of Manchester. The booklet forms a source of learning for the students themselves enabling them to learn from each other rather than from lecturers and textbooks.

It is hoped that students learn effectively and actively and this, in part, requires appropriate activities and/or stimulators being provided. Students were asked to study, Seeing and Touching Structural Concepts, at the website, www.structuralconcepts.org, where structural concepts are demonstrated by physical models and their applications are shown by practical examples. It was hoped that students could not only quickly revise a number of concepts they studied previously but could also gain an improved understanding of the structural concepts.

MANCHESTER 1824